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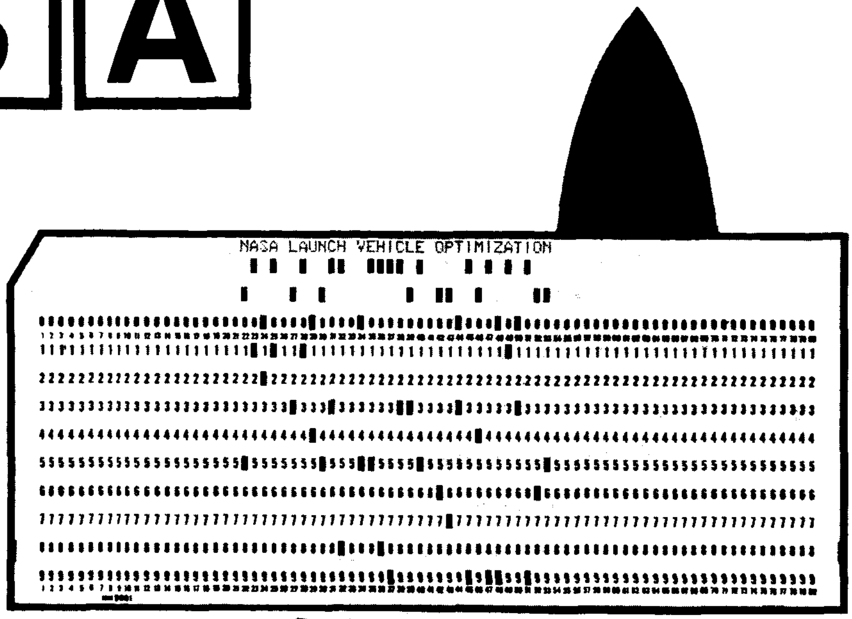
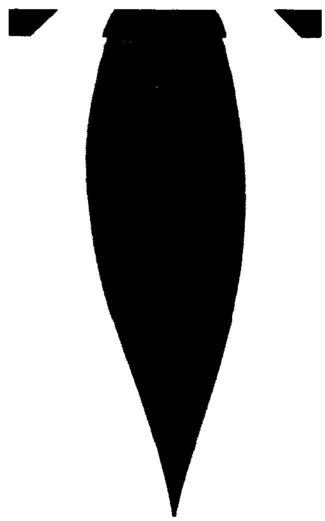





# LAUNCH VEHICLE OPTIMIZATION



## PHASE II FINAL REPORT



Volume I

Concept Development and Application

ISi

LEAR SIEGLER PUBLICATION NO. GRR-65-1089-I
to
Office of Launch Vehicle and Propulsion Program
NASA Headquarters
Washington, D.C.

# LAUNCH VEHICLE OPTIMIZATION

# PHASE II FINAL REPORT

September 1965

Prepared by
Instrument Division
Under
Contract NASw-938

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ABSTRACT

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VOLUME I

# PRESTO CONCEPT DEVELOPMENT AND APPLICATION

This first document of a three-volume final report presents and discusses a philosophy for solution of the complicated Launch Vehicle Optimization (LVO) problem and the results of an application of this philosophy to a real system -- a selected Study Launch Vehicle System (SLVS). This specific application was designed to demonstrate the feasibility and capability of the approach. The described philosophy for solution is called the PRESTO concept (for Performance, Reliability and Economics Simulation Techniques for Optimization).

Author

FOREWORD

VOLUME I

PRESTO CONCEPT DEVELOPMENT AND APPLICATION

A final report in three Volumes is herewith submitted by Lear Siegler, Inc., Instrument Division to the National Aeronautics and Space Administration Headquarters in fulfillment of Contract NASw-938. The study, entitled Launch Vehicle Optimization Study -- Phase II, was pursued under the technical direction of the Launch Vehicle and Propulsion Program Office, Code SV, NASA Headquarters, by the following participant organizations:

- LSI Instrument Division
- LSI Defense Systems Operations
- The University of Michigan

This summary report of the Phase II Launch Vehicle Optimization Study is contained in three separate volumes.

| | |
|---|---|
| • Volume I<br>Concept Development And Application | Volume I contains a general review of the program, an exposition of the PRESTO concept and techniques, a presentation of its application to a Study Launch Vehicle System, and a discussion of special problems and significant achievements. |
| • Volume II<br>Techniques Development - Lear Siegler, Inc. | Volume II contains a comprehensive review of the PRESTO simulation and optimization techniques, as formulated and applied at LSI, in addition to a description of the Study Launch Vehicle System to be analyzed. |
| • Volume III<br>Techniques Development - University of Michigan | Volume III contains a report of related efforts compiled by the University of Michigan under the direction of Dr. Frank H. Westervelt. It includes documentation on the Westervelt Performance Simulator and the U of M Regression Routine. |

# PREFACE

## VOLUME I

## PRESTO CONCEPT DEVELOPMENT AND APPLICATION

An earlier Phase I Launch Vehicle Optimization (LVO) effort, conducted under NASA Contract NASw-766, was completed early in 1964. In March of that year the Instrument Division of Lear Siegler, Inc., in cooperation with the University of Michigan and the Defense Systems Operations of Lear Siegler, Inc., was engaged under Contract NASw-938 to continue the development of the PRESTO concept and to study its application to a typical operable launch vehicle system. The Phase II program, described in this report, was originally designed to utilize most effectively the capabilities and facilities of each of the three participant organizations listed in the FOREWORD in effecting the full fruition of program objectives.

This three part document contains the entire results of the Phase II study program. Recommendations are made concerning: 1) the techniques requiring further development before effective application of the techniques can be realized, 2) suggested use of the techniques that have been demonstrated and applied, and 3) the definition of areas where both new philosophies and techniques must still be developed.

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LEAR SIEGLER PUBLICATION NO. GRR-65-1089-I

# LAUNCH VEHICLE OPTIMIZATION

# PHASE II FINAL REPORT

## 1 INTRODUCTION

This three volume document constitutes the final report of results achieved under Prime Contract NASw-938 awarded to Lear Siegler, Inc., Instrument Division, Grand Rapids, Michigan, by the National Aeronautics and Space Administration Headquarters, Washington, D. C. The study, entitled Launch Vehicle Optimization Study (Phase II), was completed under the technical direction of the Launch Vehicle and Propulsion Office, Code SV, NASA Headquarters.

Preceding this reported program, a preliminary Phase I effort was concluded under NASA Contract NASw-766 in early 1964. In March of that year the Instrument Division of Lear Siegler, Inc., in co-operation with the University of Michigan and Lear Siegler's Defense Systems Operations, was engaged under Contract NASw-938 to continue the development of the PRESTO concept (Performance, Reliability and Economics Simulation Techniques for Optimization) and to apply this concept to a typical launch vehicle system. The Phase II program, described in this report, was originally designed to utilize most effectively the capabilities and facilities of each of the three participating organizations in obtaining the full fruition of program objectives.

This three volume document contains the results of the Phase II study. The first volume describes the general program, discusses the concepts and the techniques which evolved, and also presents an application to a Study Launch Vehicle System (SLVS). It also contains a review of the problems encountered and an appraisal of the significant achievements realized during the program. Some recommendations are made concerning:

a. The techniques requiring further development before effective application can be realized,

b. Suggested use and implementation of the techniques that have been demonstrated and applied, and

c. The further definition of areas where both new philosophies and techniques must still be developed.

The second volume consists of six appendices that describe the detailed aspects of the portions of the work conducted by Lear Siegler, Inc., during the program.

The third volume consists of details of the development work performed at the University of Michigan under the direction of Dr. Frank H. Westervelt.

# 2 LVO PROGRAM SUMMARY

## 2.1 PURPOSE OF THE STUDY

NASA efforts in Launch Vehicle Optimization are presumably based on the conviction that nothing less than total success can be accepted as a design goal for all of the nation's major space programs. This degree of unqualified success is therefore to be demanded from quite a number of bold and broad-scope system development programs. To achieve such success at minimum cost necessitates the imposition of positive, yet realistic, constraints upon contractor management throughout the design and development of all respective component systems. The attainment of this end also demands the availability and useful application of the best evaluation procedures, trade-off criteria, and design decisions by NASA management personnel.

Total achievement of this required success rests ultimately on the ability of management to conduct an orderly and detailed study of each existing or proposed system in order to be able to choose the best. To choose wisely and well requires the use of modern techniques which guarantee objectivity in making realistic trade-off decisions and a comprehensive validity in the evaluation of related systems.

Clarification of these goals indicates one of NASA's recurring management problems -- that of selecting from an assortment of existing or proposed launch vehicle systems those systems which will best accomplish a set of specified mission requirements at minimal cost to the taxpayer. Performance of a valid and objective selection requires the previous orderly and efficient study of each candidate launch vehicle system and the availability of an effective method of comparing common criteria.

In the history of past performance, a number of factors have made such studies extremely difficult. Among them have been the inherent complexity of all major launch vehicle systems, the absence or non-availability of complete information in many areas, and the lack of adequate analytical tools. These difficulties are currently compounded by the additional requirement that the studies be performed on a series of launch vehicle systems whose configurations are generally very different from one another.

The ultimate objective of NASA's Launch Vehicle Optimization Study (LVO) is to be able to simulate and optimize automatically various complex launch vehicle systems in terms of such technical and operational parameters as performance, reliability, and cost. The term simulate is intended to mean the generation of algorithms which completely specify the behavior of the technical and operational parameters of launch vehicle systems, and the term optimize is intended to mean the identification of the optimum parameters of launch vehicle systems consistent with specified requirements. Any practical approach to achieving this ultimate objective must, it is believed, make use of the modern high-speed digital computer and include a most sophisticated exploration of its capability.

This objective is so broad that it could conceivably include nearly anything and everything concerning launch vehicle systems. Although this program has made some major strides toward the ultimate goal, it must be emphasized that the attainment of the ultimate goal is still many years in the future. However, this program stands in the forefront of a concerted effort to approach the specification of a launch vehicle system as a single issue. Any such ambitious project should expect problems, and indeed the program has had its share of them. The demonstrated attempt to undertake such a project is of itself significant, and the learning associated with such an attempt should prove extremely valuable to both NASA and LSI.

## 2.2 PHASE I CONTRACT

The initial effort to develop and apply a unified method for solving the launch vehicle system design and development problem was conducted under Research Contract NASs-766 awarded to Lear Siegler, Inc./Instrument Division by the Office of Launch Vehicles and Propulsion, NASA Headquarters. The basis for this effort, often referred to as Phase I, was the original work described in a dissertation by Dr. Frank H. Westervelt of the University of Michigan. Dr. Westervelt's dissertation contained two basic items, a Simulator routine and a Stepwise Regression routine with Simple Learning. The Simulator routine, which was a digital computer methodology for simulating the behavior of physical systems, constituted original work. The Simple Learning, Stepwise Regression routine, which is a digital computer methodology for constructing equations to represent data, was an extension of previously conceived techniques.

The U. of M. and Dr. Westervelt, while under contract with Consumers Power and Commonwealth Associates and prior to the inception of the Phase I program, had conducted a study on optimizing the cost of power plant design. This study added a simple cost analysis routine and an Optimization routine to the Simulator routine and the Simple Learning, Stepwise Regression routine. During the first phase of the NASA-LVO program reported in Lear Siegler, Inc., Engineering Report No. GR-1451, dated May 1964, these four routines were collectively called the System Optimization and Review Technique (SORT).

The objectives of the Phase I contract were realized in that it established the general applicability of SORT to the launch vehicle system problem, although the initial effort demonstrated that the simulation of system reliability and economics was not entirely within the scope of the SORT simulators' logic. Subsequently, techniques were postulated for handling the logic of system reliability and economics. The combination of these techniques with the earlier SORT concept of Phase I provided a more powerful concept for solving the system definition and development problem. This methodology, known as the PRESTO concept (for Performance, Reliability, and Economics Simulation Techniques for Optimization), formed the basis for the presently reported Phase II effort. This is considered to be a realistic and powerful approach to a workable solution for NASA's future launch vehicle system programs and other system problems.

## 2.3 STRUCTURE OF THE PHASE II PROGRAM

The Phase II development effort was initiated during March, 1964, and was conducted under Research Contract NASw-938 as a follow-on to the Phase I effort described in summary in the previous paragraph. The Program organization was as follows: The Instrument Division of Lear Siegler, Inc., was Program Manager responsible to the Office of Launch Vehicle and Propulsion, NASA Headquarters; and the University of Michigan and Lear Siegler, Inc./ Defense Systems Operations were participating members and subcontractors to LSI/Instrument Division.

The original intent of the program was to pursue the development, verification, and application of the PRESTO concept which had been formulated during the Phase I effort. The contract period of approximately 13 months was divided into three sub-phases, each constituting approximately one third of the total time. These sub-phases, in order, might be described as:

- Sub-phase I - The development of techniques and computer methodology to satisfy requirements of simulation, optimization, and system definition.

- Sub-phase II - The test, refinement, and documentation of these "stand-alone" techniques and the development of suitable interfacing between the techniques commensurate with the basic PRESTO concept. Sub-phase II was also to be directed toward definition of the Study Launch Vehicle System (SLVS) and the collection and grouping of data on the SLVS required for the demonstration sub-phase to follow.

- Sub-phase III - Was the period during which a launch vehicle application was to be demonstrated by the optimization of performance, reliability, and cost parameters in accordance with specified constraints.

As the program proceeded through the technique development Sub-phase I, it became apparent that certain of the techniques required more emphasis to bring them to the level of development required for the demonstration sub-phase. The program was slightly reoriented to place more emphasis on the performance simulator and to de-emphasize, temporarily, the work on the economics modeling of the system. Extreme emphasis was placed on the generation of performance models using the Performance Simulator and in attempting to construct satisfactory element descriptor libraries for this simulation.

During the course of Sub-phase II and the inception of Sub-phase III, it became apparent that the successful simulation of performance could not be accomplished with the Performance Simulator as conceived. As a result, the program was reoriented, with the concurrence of NASA Headquarters, toward the demonstration of the PRESTO concept in a somewhat restricted, although acceptable manner. It was determined that the most expedient course of action was to curtail further Performance Simulator development and to restrict the SLVS demonstration and application to the modeling of reliability and cost of the Launch Vehicle and to the optimization of cost for a family of system reliabilities.

A more detailed discussion of the conduct of the program sub-phases and their relation to the efforts of technique development, application, LVS definition, and unified concept verification are discussed in Section 3.4 of this volume. In addition, Section 3.4 contains a summary of the work accomplished by each of the participating organizations during the course of the sub-phases and description of how these tasks were reoriented to achieve the final results discussed in Section 5 of this volume (Vol. I).

## 2.4 RESULTS AND CONCLUSIONS

The results obtained from this program, although not fully meeting the objectives as originally set forth, are considered to be significant. Several major achievements have been realized, and some meaningful steps made toward the implementation of portions of the PRESTO concept. These are summarized as follows:

a. A reliability simulator called RAPID has been developed, tested, and applied using real system data. This reliability technique is considered to be a technology development and a major contribution to the analysis of reliability from the systems standpoint. The real potential of this technique has not yet been exploited within the framework of this program, primarily because of the difficulty encountered in the collection of data in the proper format or content to utilize the power of the technique.

(See Vol. II,
Appendix B)

b. An optimization program called GREAT has been developed which combines the best features of many techniques, and this program has been applied to solution of real problems including the reliability/cost study of the SLVS. Although it is extremely general in its structure, some considerable improvements can be made in making it a more powerful and general optimization program to handle a larger number of system parameters. It can also be made more user-oriented for the systems analyst through certain modifications including an improvement of input format sheets, easement in specification of constraints, output formating, etc.

(See Vol. II,
Appendix F)

c. A regression program called SCORE has been developed which combines the capabilities of previously conceived regression methods into one which represents a major improvement. This program, fundamentally, is based on a technique called Stepwise Regression and includes a procedure called Simple Learning in which the terms of the constructed equations are obtained by a learning process. This technique can be improved in such areas as best-fit criteria, statistical testing, and equation forms. It, too, can be improved so as to be more user-oriented, thereby increasing its utility for the designer and analyst.

(See Vol. II,
Appendix E)

d. Although the specific approach attempted for the simulation of performance under this contract did not yield satisfactory results, concurrent study and investigation of applicable techniques under development have resulted in a promising program based on the use of linear-graph theory and matrix algebra to form "state-models" of a system. These state-models can be manipulated by the use of Taylor Series expansion to place the model in a form compatible with the PRESTO concept.

(See Vol. II,
Appendix A)

e. A successful attempt has been made to model and optimize cost/reliability for a launch vehicle. Although the reliability model was constructed for single order failures only and the cost model was essentially primitive in nature (both conditions due to the scarcity of proper data), a cost/reliability optimization for the study launch vehicle system was completed. This is significant in that the interfacing of the PRESTO technique to perform the complete systems analysis using the digital computer has now been demonstrated.

(See Vol. I,
Section 5)

f. The collection of data necessary for the present study was fraught with the classical problems of data handling. The desire to keep the data unclassified imposed many constraints. The approach taken was to provide data sufficient to demonstrate the utility of PRESTO, without indicating that the data had complete validity, and to seek a convergence between data requirements and data availability.

It is necessary that future developments of this nature be based on not only the technique and the power of approaches but also on the data required for their implementation.

g. A significant insight was gained into the problems and approaches associated with the automatic generation of computer programs by the digital computer, itself. From the standpoint of future developments, this is perhaps the most significant achievement of the Phase II contract.

Since it is felt that the above results of this contract are of significance to NASA for future use, the following recommendations are being made in order to exploit the knowledge gained.

a. It is recommended that NASA start to apply the RAPID technique to the reliability analysis of systems involving higher order failures to gain experience in, and to disseminate information regarding the use of this powerful tool. Additionally, it is recommended that NASA concentrate on extending the RAPID technology to a more generalized Probabilistic Mode Analysis technique and investigate one or two possible methods of automatically generating the System Mode Arrays for the input to RAPID. Some further work in the definitions and generation of reliability library functions and structure is recommended also.

b. It is recommended that NASA apply GREAT and SCORE to some specific problems to further evaluate their utility in the optimization of systems of equations, and the generation of system models from raw data. Improvements as discussed above should also be incorporated.

c. It is recommended that NASA seriously consider instituting a study pointed toward the demonstration of feasibility of constructing a performance simulator utilizing the technique discussed in Vol. II, Appendix A, of this report.

d. Finally, it is recommended that NASA maintain a continuous effort to develop techniques for the automatic computer generalization of parametric and algebraic models suitable for use in the analysis of generalized systems configurations.

# 3 LVO PROGRAM

## 3.1 PROBLEM STATEMENT

NASA is confronted with the requirement of selecting from a collection of existing or proposed launch vehicle systems those systems which will accomplish specified mission requirements at maximum system effectiveness as defined by NASA Management. This selection requires an orderly and efficient study of each candidate launch vehicle system.

The inherent complexity of a launch vehicle system, the absence of complete information in many areas, and the lack of adequate analytical tools has made this task of system selection extremely difficult. The difficulty is compounded by the additional requirement that launch vehicle systems whose physical configurations are generally very different must be objectively compared in the areas of interest.

## 3.2 PRESTO - AN APPROACH TO PROBLEM SOLUTION

The methodology advanced as a solution to the general systems problem is PRESTO*, a concept which can be described simply as the implemented philosophy of system simulation, analysis, and evaluation through dynamic utilization of the digital computer. The PRESTO concept is illustrated in Figure 3-1.

The heart of the concept is the Element Descriptor Library. The contents of the Library are provided through the following;

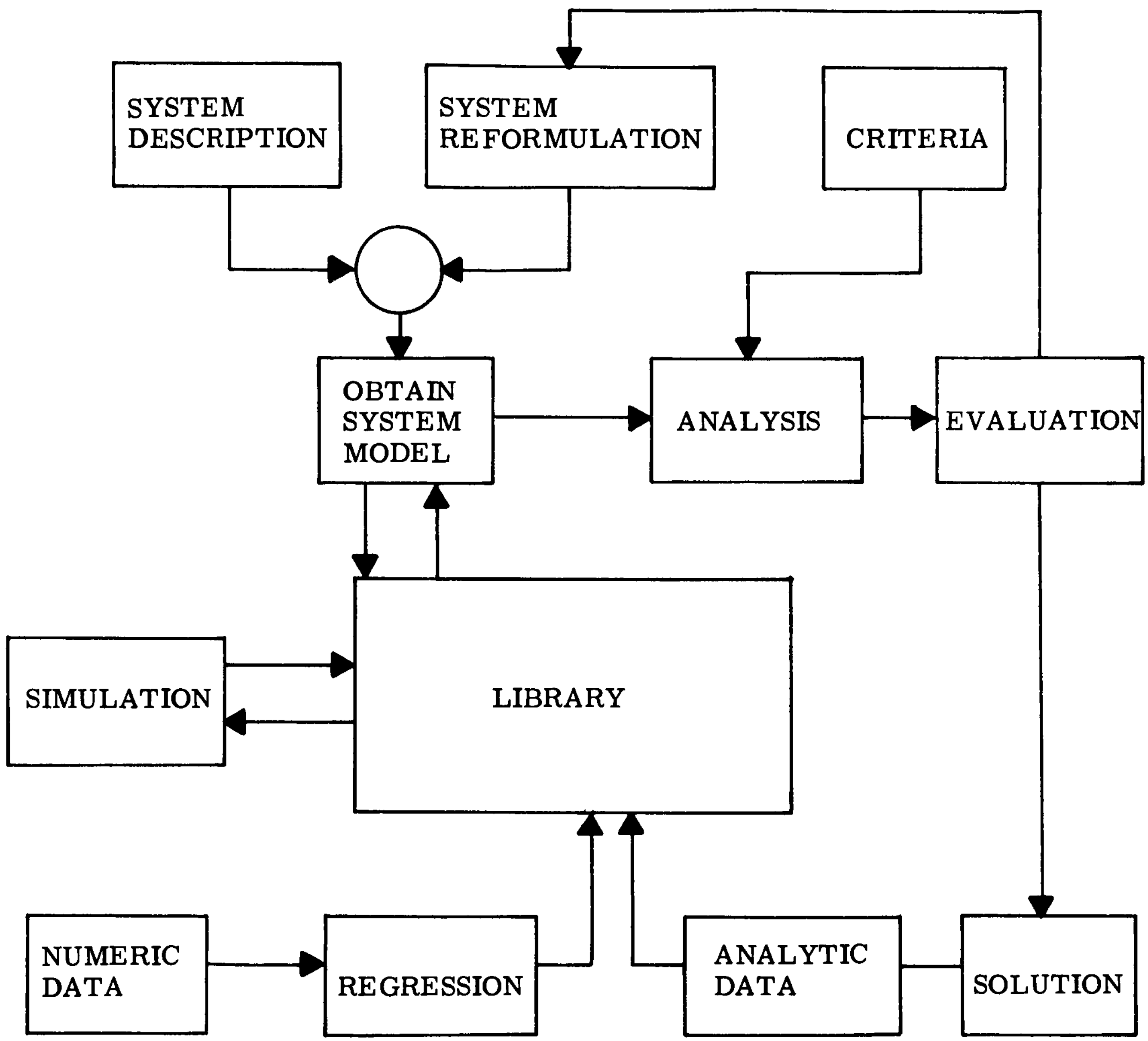
a. Direct insertion of analytical data in the form of a mathematical model,

b. Reduction of numeric data into the form of a mathematical model by means of regression techniques, and

c. Construction of a mathematical model by means of a simulation process which interweaves previously constructed models existing in the Library to form a model on a higher level.

The System Description consists of a delineation of the elements comprising the system and their interconnections along with a description of the system parameters of interest and those which will be supplied during the analysis phase. The Library is then searched for a model

*Performance, Reliability, and Economics Simulation Techniques for Optimization




PRESTO CONCEPT
FIGURE 3-1

of the system. If the exact model already exists in the Library, no further work is necessary before entering the analysis phase. If the model does not exist, it is constructed through use of the Library-Simulator combination and stored in the Library for possible future use.

The simulation phase of the total philosophy may be defined as the process of formulating mathematical models which describe system behavior. In totality, system behavior includes consideration of all system characteristics. A practical and important subset of the total, i.e. performance, reliability, and economics, has been utilized in the demonstration of the solution philosophy.

The analysis phase of PRESTO may be thought of as any numerical evaluation of the mathematical models generated by the simulation phase. Analysis, as just defined, could be an optimization procedure which, in a general sense, is the identification of system parameter values that maximize (minimize) some system index consistent with specified requirements by a systematic numerical evaluation of the proper mathematical models.

The evaluation portion of the concept consists in the assessment of the results of the simulation and analysis phases. Within the scope of the evaluation phase might be included tasks such as the determination of the validity of solutions to the system problem, the objective choice of the "best" solution, and the unique capacity to decide whether system reformulation is required to achieve the solution goals.

The development of an efficient computer program which will automatically accomplish the objectives of PRESTO requires a great deal of ingenuity and forethought. Although the development of a completed PRESTO is still in its infancy, the requirement of utilizing an Element Library has been established.

In the Library, which is physically contained in a computer storage device, are found mathematical descriptions of the behavior of basic elements from which more complex systems can be modeled and, in turn, stored in the Library. From a Library so constructed, eventually any system might be studied, provided, of course, that all required elements have been described and stored.

## 3.3 PROGRAM OBJECTIVES

The general concept of system simulation, analysis, and evaluation involves a study of many diversified system characteristics. However, the development and demonstration of this concept relative to a defined Launch Vehicle System in the areas of Performance, Reliability, and Economics (PRESTO), were determined to be realizable objectives for the subject program which, when accomplished, would provide satisfactory verification of the overall concept.

## 3.4 PROJECT MANAGEMENT AND TASK COORDINATION

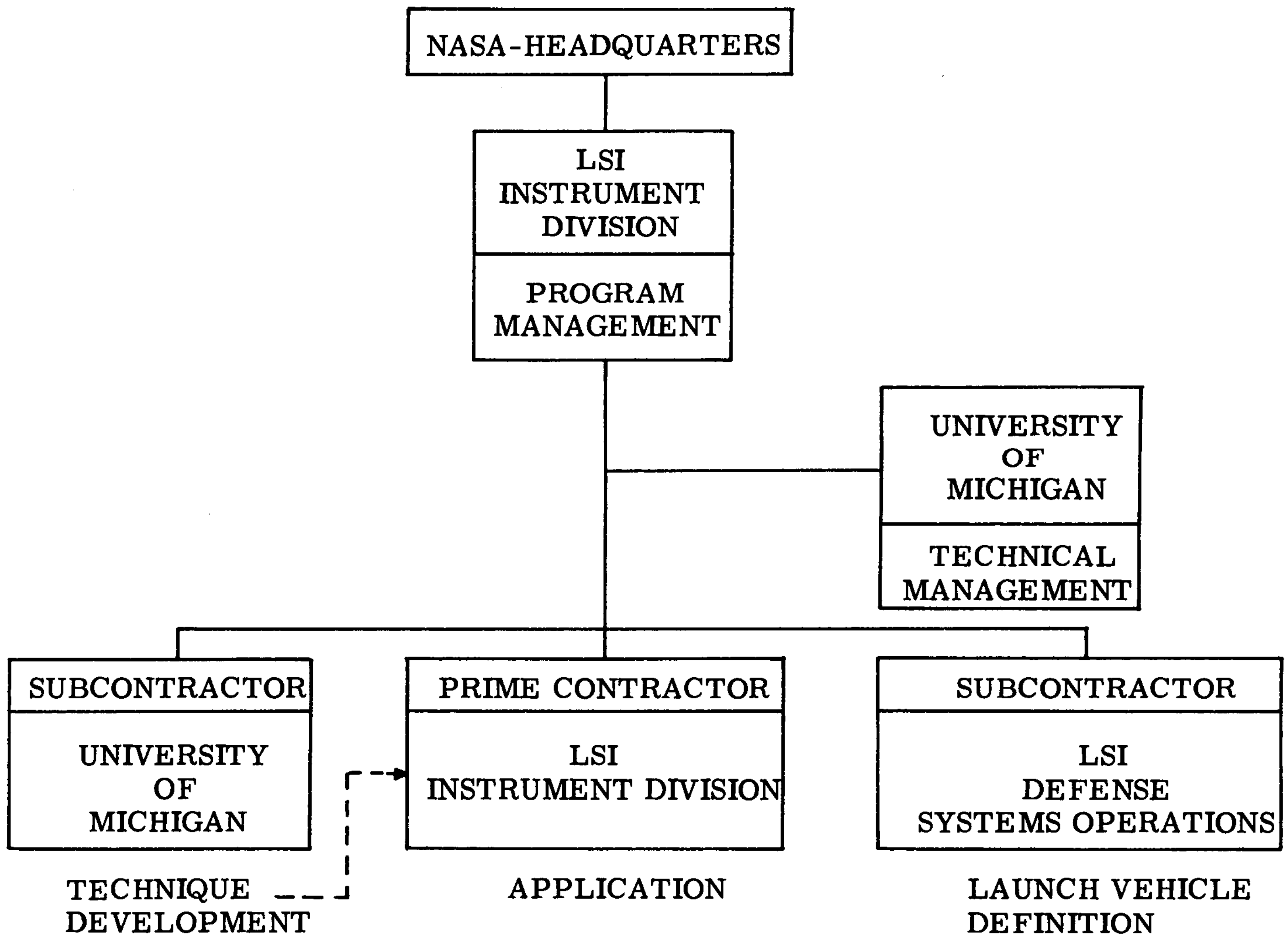
### 3.4.1 Overall Program Management

The Phase II portion of the NASA LVO study was organized originally to provide a division of effort commensurate with the capabilities and interests of each of the participating organizations. Figure 3-2 shows a simple management chart and indicates the major divisions of effort which were assigned at that time.

Management of the program was assumed by LSI/Instrument Division with technical management being assigned to the University of Michigan. The subcontractors, in cooperation with LSI/Instrument Division, assumed the following responsibilities: University of Michigan - Technique Development; LSI Defense Systems Operations - Launch Vehicle System Definition; and LSI Instrument Division - Application.

Some shifting of responsibility occurred as the program evolved, and resulted in major portions of the technique development and technical management being assumed by the Instrument Division as indicated by the dotted line on Figure 3-2. The basic reasons for such shifts will become more apparent as various detailed responsibilities are further discussed.

As was previously mentioned in Section 2.3, the program was basically divided into three sub-phases: Sub-phase I - Technique Development, Sub-phase II - Test and Documentation, and Sub-phase III - Application and Demonstration. Sub-phase III also contained a contract extension period of three months during which the remaining work on the program was completed.




PHASE II CONTRACT RESPONSIBILITIES
FIGURE 3-2

### 3.4.2 Responsibilities and Assignments

Specific areas of responsibility are shown in Figure 3-3, both as originally assigned and as revised during the ensuing sub-phases.

#### 3.4.2.1 Sub-phase I

University of Michigan

During Sub-phase I, the University of Michigan's responsibilities were basically in the following areas:

a. Optimization

A basic optimization program was available at the beginning of the contract period. This was to be further developed and modified as required to fit into the overall LVO study.

b. Regression

A basic regression program was also available at the beginning of the contract period. This was to be further developed and modified as required to fit into the overall LVO study.

c. Performance Simulator

The Performance Simulator program was in the process of being converted from the IBM 704 to the IBM 7090 digital computer at the beginning of the contract period. This conversion process was to be completed, and the program was to be further developed and modified as required to effect consistency with the overall concept.

d. Reliability and Economic Simulators

At the conclusion of the Phase I study it became apparent that the approach of employing the Performance Simulator to model system reliability and economics was not feasible for a complete analysis in these areas. At this point, reliability and economics were broken out as separate areas of study for which simulators would be required. Therefore, at the beginning of the Phase II effort the areas of reliability and economics were spelled out as unique areas

| UNIVERSITY OF MICHIGAN | LSI-INSTRUMENT DIVISION | LSI-DEFENSE SYSTEMS OPERATIONS |
|---|---|---|
| **SUB-PHASE I** | | |
| 1. Performance Simulation<br>2. Reliability Simulation<br>3. Economics Simulation<br>4. Optimization<br>5. Regression<br>6. Documentation<br>7. Data Processing | 1. Program Integration<br>2. Library Development with D. S. O.<br>3. Documentation Coordination | 1. Launch Vehicle Definition<br>2. Performance Simulation Data<br>3. Library Development with I. D.<br>4. Documentation |
| **SUB-PHASE II** | | |
| 1. Performance Simulation<br>2. Regression with I. D.<br>3. Documentation<br>4. Data Processing | 1. Program Integration<br>2. Library Development with D. S. O.<br>3. Optimization<br>4. Reliability Simulation<br>5. Economics Simulation<br>6. Documentation | 1. Launch Vehicle Definition<br>2. Performance Simulation Data<br>3. Library Development with I. D.<br>4. Documentation |
| **SUB-PHASE III INCLUDING CONTRACT EXTENSION** | | |
| 1. Documentation<br>2. Data Processing | 1. Program Integration<br>2. Library Development (minor)<br>3. Optimization<br>4. Regression<br>5. Reliability Simulation<br>6. Economics Simulation<br>7. Documentation<br>8. New Techniques Study | 1. Launch Vehicle Definition<br>2. Reliability Library Development<br>3. Reliability Data<br>4. Economics Library Development<br>5. Economics Data<br>6. Performance Data<br>7. Documentation |

PROJECT TASK ASSIGNMENTS
FIGURE 3-3

of responsibility for the University of Michigan along with performance simulation, optimization, and regression, and the general area of documentation.

e. Data Processing

Since the majority of the programs were originally anticipated to be very large and require a high-speed, high-capacity digital computer, continuing arrangements were made with the University of Michigan to utilize the IBM 7090 Computer at the University of Michigan Computing Center.

Lear Siegler, Inc./Instrument Division

The responsibilities assumed by Lear Siegler, Inc./Instrument Division were in the following areas:

a. Program Integration

The responsibility for coordinating and integrating the efforts of the University of Michigan, Lear Siegler, Inc./Instrument Division, and Lear Siegler, Inc./Defense Systems Operations, was assumed by the Instrument Division. A program manager was named to perform this liaison along with direct liaison with the technical director at NASA Launch Vehicle and Propulsion Office.

b. Library Development

The development of the library for the Launch Vehicle System was originally assigned as a joint effort between the Instrument Division and the Defense Systems Operations of Lear Siegler, Inc.

c. Documentation

In an attempt to coordinate the documentation requirements on the program, Lear Siegler, Inc./Instrument Division assumed responsibility for these documentation efforts.

Lear Siegler, Inc./Defense Systems Operations

The Defense Systems Operations of Lear Siegler, Inc. was assigned basic responsibility in the following areas:

a. Launch Vehicle System Definition

A broad and general definition of the Launch Vehicle System was available at the beginning of Phase II, but was not in a form suitable for demonstration of the PRESTO methodology. Defense Systems Operations assumed the responsibility to continue this definition and delineate the various levels of the system to be studied.

b. Performance Simulator Data

In conjunction with the Launch Vehicle System Definition, Defense Systems Operations was to collect and prepare data on the defined system in a form suitable for use as input to the Performance Simulator for generation of a performance model.

c. Library Development

Development of a library for the Launch Vehicle System was originally assigned as a joint effort for the Instrument Division and the Defense Systems Operations. However, because of the increased responsibility assumed by the Instrument Division in their areas of the program, this responsibility was later assigned entirely to the Defense Systems Operations. In addition, Defense Systems Operations was to provide documentation to cover its development efforts.

3.4.2.2 Sub-phase II

As Sub-phase II progressed, certain shifts in work assignments were made to place concentration on areas of the program which required more effort to achieve the final results desired.

a. Performance Simulation

As it became apparent that the majority of the effort of the University of Michigan was being required for the conversion of the Performance Simulator to the 7090, the responsibility for the development of the reliability and economics simulators was transferred to the Instrument Division. Several problems had also been encountered in the Performance Simulator which required concerted effort to modify the approach in an attempt to simulate the performance of the Launch Vehicle System.

b. Reliability Simulation

As cited above, it appeared beneficial for the overall program that the responsibility for the reliability simulation development be allocated to the Instrument Division. The approach in this area had been previously conceived and proposed by the Instrument Division. As a result, it appeared that the reassignment was the most efficient method of keeping the efforts in the area of reliability concurrent with those of performance.

c. Economics Simulator

Responsibility in this area was assigned the Instrument Division of LSI because of the concentration of effort on the Performance Simulator at the University of Michigan.

d. Optimization

Responsibility in this area was also undertaken by the Instrument Division of LSI in order to assure overall compatibility of the various simulators involved in the PRESTO methodology.

e. Regression

Responsibility in this area was likewise assigned to the Instrument Division of LSI in order to assure a proper inter-relationship between the regression program and other programs involved in the PRESTO methodology. The University of Michigan, however, continued some development work pointed to improving the technique.

f. Library Development

Because of the increased workload at the Instrument Division, total responsibility was delegated to Defense Systems Operations for the overall library development.

3.4.2.3 Sub-phase III

During the final portions of Sub-phase III, which includes the contract extension period, it was determined that the Performance Simulator would not adequately meet the requirements of generating a model of the Launch Vehicle System. At this point the development of the

Performance Simulator was suspended, and concentration was directed toward the demonstration and application of PRESTO to the Study Launch Vehicle System discussed in Section 5 of this volume. A low level study of new techniques for the simulation of performance was undertaken at Instrument Division, resulting in work presented in Appendix A, Volume II. Figure 3-3 shows the final work assignments as they existed in Sub-phase III of the NASA Launch Vehicle Optimization Program.

## 4 PRESTO CONCEPT DEVELOPMENT

The approach pursued in this program has included the following efforts:

a. To develop the simulation phase of PRESTO to the extent of achieving the capability of modeling system Performance, Reliability, and Economics,

b. To develop an Optimization method for the analysis phase of PRESTO,

c. To develop a regression routine to assist in the formulation of an Element Descriptor Library, and,

d. To demonstrate the applicability of the PRESTO concept to a defined system.

Within the simulation phase, the exact nature of the system model being constructed is a function of the system parameters and coefficients which are of interest in the overall problem solution. These, in turn, are related to those characteristics and properties of the system which are to be considered in the analysis phase. As mentioned above, the parameters selected for consideration are performance, reliability, and economics (cost).

The definition of system performance as used in this discussion is that measure of how well a system is performing its assigned function, assuming that all components are behaving in a predefined manner. Performance, therefore, is a function of:

a. System configuration,

b. System component parameters or coefficients, and

c. Tolerances on the system component parameters or coefficients.

System reliability will be defined as a measure of the probability that a system will be operating in some predefined manner after a certain length of time in a specified environment. Reliability is a function of:

a. System configuration,

b. System component reliability, and

c. Environment.

System cost will be defined as that cost accrued in obtaining the system components, their assembly, shipping, inspection, and ground support. Cost is a function of such things as:

a. System configuration,

b. System component tolerances,

c. System component reliabilities, and

d. Other factors.

Those parameters or items which are common to more than one of the areas of performance, reliability, and cost are the type of parameters which can be adjusted and optimized. Those of immediate interest are:

a. System configuration,

b. Component tolerances or accuracies, and

c. Component reliabilities or failure rates.

Once these parameters of interest have been established, an Element Descriptor Library can be constructed.

For example, in the area of performance for a resistor, the Library would contain Ohm's law as one of the functional parameter relationships. For a subsystem such as guidance, the Library might contain a "state model" or set of differential and algebraic equations relating parameters and coefficients existing in the subsystem as a function of time. Such a state model could conceivably have been generated by a prior simulation. Similarly, models for reliability and cost may vary in complexity. As various types and levels of subsystems are simulated, the resulting mathematical models are stored in the Element Descriptor Library for later use. Thus, as the Library becomes more and more complete, the amount of detail involved in complex system simulation is reduced. System simulation which was previously impossible to any degree of accuracy becomes increasingly practical.

It should be emphasized that the development of a computer simulator program capable of constructing a mathematical system model, or state model, through interweaving the mathematical models of the subsystems comprising that system, is no minor task. However, it should also be emphasized that this approach appears to be the only satisfactory answer if digital computers are to be used effectively in the solution of these problems. Once a system has been simulated adequately in the form of mathematical models on the digital computer, the evaluation of such a system becomes efficient and accurate. Such efficiency of evaluation is required in order to optimize the system within a reasonable length of time.

The approach to optimization in this study has been to minimize the overall cost of a launch vehicle system while maintaining certain pre-established requirements on system performance and reliability. Obviously, other choices could be made such as maximizing the system reliability while maintaining requirements on cost and performance.

A more detailed discussion of the specific areas of interest in the overall PRESTO concept development follows.

## 4.1 PERFORMANCE SIMULATION

System performance simulation involves the generation of a mathematical model which will predict how well the system performs the functions desired of it, assuming that all components comprising the system are operating in a predefined manner. Such a model should express system performance specifications as a function of the component performance specifications.

Initial efforts in the development of a digital computer program which would automatically generate a performance model were directed towards use of the simulator program developed at the University of Michigan by Dr. F. H. Westervelt. This simulator was designed to generate a mathematical model capable of computing system parameter values for a given set of component parameter values. The generated model would not directly compute system performance specifications for a given set of component performance specifications. However, it was felt that the use of this mathematical model and the application of Monte Carlo techniques and regression analyses would result in the type of model desired. These techniques could then be combined so that a true performance model could be generated automatically.

Considerable effort was expended towards establishing a working version of the Westervelt Simulator on the IBM 7090 at the University of Michigan. Problem areas which developed in attempts to find the solution of dynamic systems and in checking for non-trivial solutions were remedied for certain types of problems. Efforts to obtain a performance model for the Study Launch Vehicle System resulted in some difficulties. Most of these difficulties may be resolvable, given enough time and effort. However, the current status of the Performance Simulator is such that a suitable performance model of the Study Launch Vehicle System is not obtainable.

The Westervelt Simulator routine is a unique approach and unique approaches to any problem are difficult to pursue. A big disadvantage is that it is inefficient. There are, to be sure, other problems associated with the Simulator. However, it is conceivable that the disadvantages which are obvious today may be overcome or at least minimized by future advances in the hardware and software of digital computers. Even if it is never able to solve the launch vehicle system type of problem, it should not be discarded.

The basic concept of the Westervelt Simulator is very simple. The fact that numerous complexities are added in the implementation of this concept on a digital computer does not alter its basic simplicity.

To understand this basic concept, consider a system whose behavior can be described by a set of system variables. Let this set of variables be categorized into three sub-sets: a desired variable, intermediate variables, and the specified variables. The desired variable, y, is the system variable whose behavior is sought. The intermediate variables, $x_i$, are those system variables used in relating the desired variable to the specified variables. The specified variables, $z_j$, are system variables whose behavior is known. If the desired variable can be related to the specified variables, then the system behavior in terms of the desired variable can be said to have been simulated. For example, $y = g(z_j)$ would be a satisfactory solution if the function, g, were known. The basic objective of the simulator is to generate such solutions.

Associated with the Simulator is an Element Descriptor Library which contains a complete physical description of the behavior of each element. The Simulator searches through the system, calling on the Element Descriptor Library to relate the desired variable to the specified variables.

Consider the following example. The Simulator exhaustively searches each capability statement in the Element Descriptor Library until a functional relationship for the desired variable is found. Assume this is $y = f_1(x_2, x_3)$. Additional searches of this type are then initiated to determine a functional relationship for each intermediate variable in $f_1$. Assume relationships for $x_2$ and $x_3$ were found to be $x_2 = f_2(z_1)$ and $x_3 = f_3(z_2)$. From these three relationships, an algorithm can be constructed which is entirely equivalent to the solution sought. It is obvious, however, that this search process is indirect and inefficient.

As stated previously, the intent of the Simulator is to obtain an algorithm which relates a desired variable to the specified variables. In even the most simple of systems with complete element descriptions, it is frequently not possible for the search logic of the Simulator to generate such an algorithm. This situation was recognized during the development of the Simulator. When this occurs, it is still possible frequently to relate the desired variable to itself. For example, in its search, assume that the Simulator is able to determine that $y = f_1(x_1)$. Also assume that additional searching is able to determine only that $x_1 = f_2(y)$ which implies that the generated program must utilize aniniteration process. That is, a value of y will be estimated and then the estimated value of y will be used to compute a value of y. The estimated and computed values of y will then be used to arrive at a new estimated value of y. The process will be repeated until the difference between the estimated and computed values of y satisfies some criteria.

In any iteration process there are three things which may occur: convergence, divergence, or oscillation. Of these three, only convergence is desired. Convergence and divergence can be expected to occur with approximately the same frequency while oscillation can be expected to occur less frequently than the others. Thus a solution is not assured with the use of the iteration process. Even when the solution is obtainable, the use of an iteration process makes the Simulator inefficient. Since the use of the iteration process occurs with a high frequency, and often many times within the same problem, this is an important problem.

The Westervelt Simulator produces an algorithm which computes the value of some system variable. This algorithm is in the form of a digital computer program and, as indicated above, makes frequent use of iteration. There is the possibility that invalid interation solutions will be generated. For example, in its search, the Simulator is able to determine that $y = f(x_1)$. Additional searching is able to determine only that $x_1 = g(y)$. The Simulator would classify this as an iteration process. However, if it were possible to simplify the two equations to a single equation, the results might be $y = h(y)$. It is definitely possible that $y = h(y)$ is $y = y$. This is a trivial solution since any guess for the value y leads to a computed value which is the same. The estimated and computed values of y invariably satisfy any convergence criteria and the Simulator may call this a satisfactory solution.

The Westervelt Simulator has five basic types of results. There are:

a. Valid Solution

b. Valid Iteration/Converging Solution

c. Invalid Iteration/Diverging Solution

d. Invalid Iteration/Oscillating Solution

e. Invalid Iteration/Trivial Solution

f. No Solution

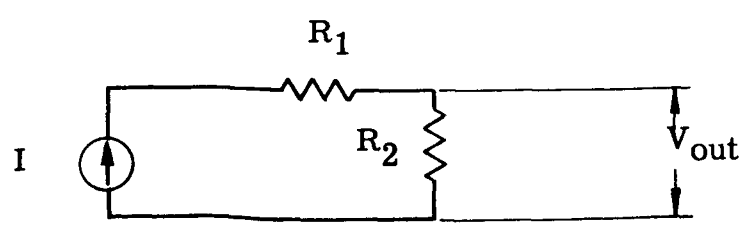
Thus the Simulator has numerous problems. Some and possibly all of them are solvable, but it is clear that a great amount of fundamental work is required before it can be considered practical. Once all the technical problems have been solved, the matter of efficiency still poses a serious question.

A description of the logic used in the Westervelt Simulator, along with a manual explaining how to use the Simulator, is given in Part A, Volume III of this report. Effort expended towards simulating subsystems of the Study Launch Vehicle is documented in the form required for use of the Westervelt Simulator, in Appendix D, Volume II. Some of the problems encountered in the actual running of the Simulator for these subsystems are discussed in Section 5.2.2.1 of this Volume.

As effort was being expended in the performance simulation area, a very basic problem continued to present itself, namely, the difficulty of defining precisely the term "system performance." Various persons have differing ideas as to what is meant by the performance of a system. One example is the term performance as applied to a guidance subsystem. In this case a measure of the system performance might be the circle of error probability (CEP) associated with the particular guidance subsystem. This interpretation has the connotation of system accuracy or precision. A performance simulation of a guidance system would then require the construction of a mathematical model which would relate system accuracy to the accuracy or precision of the various components making up the system.

However, even with a clearly defined definition of performance, the problem is not solved. The usual concept of a mathematical model for a guidance system is one which relates position and velocity errors in time as a function of component parameter or coefficient values. This model does not relate the distribution of position and velocity errors or accuracy as a function of the distribution or accuracies of the components. This is the type of relationship necessary in the PRESTO concept.

A simple example will illustrate the problem. Assume a network composed of a current source of nominal value, $I_{nom}$, in series with two resistors of nominal value, $R_{1nom}$ and $R_{2nom}$, respectively.



It is desired to compute the output voltage, $V_{out}$. The mathematical model for this system is simply

$$V_{out} = I \times R_2.$$

However, this relationship does not relate the distribution characteristics of the output voltage to the distribution characteristics of the resistors and the current source. Assuming a value for the standard deviation of the current source to be $\sigma_I$ and the standard deviations for the resistors to be $\sigma_{R1}$ and $\sigma_{R2}$, the standard deviation of the distribution of the output voltage is approximated by[1]

$$\sigma_{V_{out}} = \sqrt{I_{nom}^2 \cdot \sigma_{R2}^2 + R_{2\,nom}^2 \cdot \sigma_I^2} .$$

This equation, together with the equation for $V_{out}$ given previously, constitute the performance model of the network for the system parameter of interest, namely the output voltage.

Determination of the performance model for a system becomes increasingly difficult as the complexity of the system increases. One approach would be to use Monte Carlo techniques on the mathematical model. This involves the repeated solution of the mathematical model in order to establish a distribution for the system output parameters for a given set of distributions on the system components. This is then repeated over and over for other sets of distribution characteristics on the components and the computed distribution characteristics on the system output parameters must then be related mathematically through the use of regression techniques.[2]

[1] Bowker and Lieberman, "Engineering Statistics," Prentice-Hall Inc., 1959 (pp. 40-66).

[2] The regression routine developed under this contract is described in detail in Appendix E, Volume II of this report.

This approach involves a very large number of computations and no good way of determining the resulting accuracy of the model is available.

In summary, three basic areas need development in performance simulation:

a. Definition of system performance,

b. Efficient and rigorous generation of system "state models", and

c. Practical exercising of these "state models" in order to obtain functional relationships of the performance parameter distributions.

It is felt that the first area, the definition of system performance namely, can best be developed through much joint discussion and thought on the part of those people who are vitally interested and experienced in this area.

In the second area, the efficient and rigorous generation of system "state models" namely, problems existing in the use of the Westervelt Simulator prompted an investigation into other similar computer simulation techniques. Hopefully, a method could be found that was based on a slightly stronger mathematical foundation and thus would provide a better insight into the problems that are associated with the automatic generation and solution of a system model. A general, orderly, efficient and mathematically rigorous modeling technique was sought.

One technique that was found to satisfy the above criteria is the Michigan State System Analysis Program (MISSAP) that is being developed at Michigan State University under the sponsorship of International Business Machines Corporation. This program uses various aspects of linear graph theory to generate a state model for the system under study.

Although the present version of the program is primarily restricted to linear electrical networks, the general state model formulation technique is extendable to include a large number of other non-linear, multi-terminal components. This has been verified in the electrical case by the inclusion of a non-linear transistor model in a recent version of MISSAP. A detailed discussion of this approach is outlined in Appendix A of Volume II.

Also included in Appendix A of Volume II is a discussion of various approaches which might be used in order to satisfy the third requirement, namely the exercising of system "state models" in order to obtain a true performance model.

Much work remains to be done in the area of performance simulation. However, many interesting and promising approaches to the problem are being made and should be pursued in order to use fully their potential capabilities for solving the complex systems simulation problem.

## 4.2 RELIABILITY SIMULATION

System reliability simulation involves the generation of a mathematical model of the system from the reliability viewpoint. The reliability of a component existing in the system may be described as the probability that the component will be operating in some predefined manner after a certain length of time in a specified environment. A mathematical model is required which expresses this probability (i.e. the system reliability) in terms of the reliability of the components comprising the system.

In the past, reliability analysis of complex systems has been carried out using one of two alternate approaches. Either the system is considered as a "series system" (no redundant components) with the system reliability model being the familiar "sum of failure rates" expression involving the exponential function, or the system model is generated manually through painstaking effort which takes a relatively long period of time.

The first approach is often acceptable for preliminary analysis early in the system design phase, regardless of any known (or unknown) redundancy situations. However, this cannot be considered valid as a final analysis approach unless the system is truly a series system, where the components can all be shown to follow the exponential failure distribution. If some system components are better described by another failure distribution, such as the Wiebull, for example, the system model involving summation of failure rates is completely invalid. It is obvious that for systems involving a relatively high order of redundancy, or for multimodal systems, the second approach, stated above, while valid, can become extremely complicated. Many mathematical techniques have been developed in the past decade to aid in analyzing certain redundant configurations, but a good deal of manual effort is still required.

Some techniques for constructing a system reliability model using digital computers in various capacities have been developed in the past few years. These generally employ the computer in a passive manner to calculate the probabilities needed in the reliability model from various probability distributions known for the system elements, or to perform Monte Carlo analyses to arrive at a model. The great need that has existed in the field of reliability simulation and analysis, however, has been a computer technique having the more broadened scope of employing the computer in a dynamic sense to automatically generate the reliability mathematical model by active character manipulation in addition to using it in the passive computational mode.

The concept of automatically generating a reliability model involves a system description in a form which can be used by a simulator computer program to express the system mode probability in terms of the element mode probabilities. The system may be multimodal, in which case the simulation should produce multiple models, one for each system mode.

During the period covered by the NASA-LVO contract, a reliability simulation technique which meets the needs stated above was developed and programmed for the IBM 1620 and IBM 7090 computers. This technique, known as RAPID*, generates automatically the system reliability model as a sequence of computer program statements and outputs them in the form of a complete computer subprogram which can be executed immediately without the necessity of any adjustments or human intervention. This program serves as the means of evaluating the model, when desired. The RAPID simulators are capable of combining elements having differing failure distribution functions, since the model is in terms of element mode probabilities which are determined for each element prior to evaluating the system model. The element descriptions include a code for designating the appropriate function to be applied to the element.

The individual elements may be hydraulic, electrical, mechanical, pneumatic, or any combination of these. No limitation exists on the number of element failure distributions, since the functions can each be programmed and stored as a set of library programs to be called whenever needed.

Currently available reliability simulators employing the RAPID methodology will perform an entire system simulation and reliability computation automatically. If only the system model is desired, program intervention can be made prior to the computing phase.

Appendix B of Volume II presents a detailed discussion of the RAPID methodology and the input data required for the simulators. In addition, the IBM 1620 and the IBM 7090 Simulators are fully documented with examples given.

It is felt that an extension of reliability simulation employing the digital computer lies in the area of modeling multimodal systems with the use of Markov Processes. The states of a system as a function of time, for example, can be expressed by a Markov Process defining how transitions are made among the possible system states. This involves the study of conditional transition probabilities, which express the probability of the system being in a certain state of time t, given the system conditions at time t-T. That is, past history serves to define future system conditions.

*Reliability Analysis and Prediction Independent of Distributions

Generally, the application in the field of reliability assumes constant transition probabilities (failure rate constant with time), thus reducing the problem to stationary Markov Processes only. The continuous Markov Process seems to be a more valid approach in system reliability analysis, however, because it is often true that the transition probabilities of the system states are time dependent. It should be noted that by exercising care in defining the system, certain non-Markovian (continuous) processes can be reduced to stationary ones. It is felt that further investigation into the field of Markov Processes may yield a computerized methodology for system reliability simulation similar to, or possibly in conjunction with, RAPID.

## 4.3. ECONOMICS SIMULATION

System economics simulation involves the generation of a mathematical model which expresses system cost as a function of operational parameters of its elements. These operational parameters serve to describe system performance and system reliability.

The initial efforts in the development of a digital computer methodology which would automatically generate a system economics model were directed toward the utilization of the Westervelt Simulator. In this capacity, the Simulator served merely as a tool to sum mathematical expressions representing the costs of the elements composing the system in order to form an expression representing total system cost. With little thought, it can be seen that the greater task within the proposed economics simulation methodology lay not in the "simulation" itself, but in the determination of the element cost expressions for insertion in the Element Descriptor Library.

The determination of element cost functions involves:

a. The compilation of element cost data; , and

b. The application of regression analyses to the cost data in order to determine the mathematical expressions which relate element cost to the reliability and performance parameters.

A discussion of the many aspects involved in the compilation of element cost data of a complex system is included in Appendix D, Volume II, "Launch Vehicle System", while Appendix E, Volume II describes the concepts of regression in considerable detail.

As has been previously mentioned, problems within the Westervelt Simulator prohibited its utilization in the demonstration of the PRESTO concept. This affected the economics portions of the PRESTO demonstration in two areas:

a. Performance considerations were excluded in the data compilation, and hence in the cost model;

b. The resultant cost model utilized in the demonstration was generated by hand.

A detailed discussion of economics simulation is contained in Appendix C, Volume II.

## 4.4 REGRESSION

A large portion of the effort expended toward developing the PRESTO concept has been in the area of constructing mathematical models. Generally speaking, there are two basic types of model construction in the area of systems analysis. One type has for its source of information a description of the way in which system components are interconnected, a description of the components themselves, and a description of those variables which will be supplied to the system and those which must be computed. Constructing a mathematical model on this basis has been called simulation.

A second type of model construction has for its source of information sets of numeric data which may have been obtained by measurements in the laboratory or possibly through use of a Monte Carlo analysis of a system or component. It is often desirable to mathematically relate these variables for which numeric data are available. This type of mathematical model construction is referred to as regression analysis.

The areas of applicability of regression analysis techniques in the PRESTO methodology are numerous. Included in these are the construction of element descriptions for the Element Descriptor Library and the construction of models which simulate system performance, reliability, and cost where the usual simulation or model construction is prohibited due to lack of the proper type of information. The intended role of the regression routine in the PRESTO methodology is to replace, augment, or assist the other routines as required.

The regression routine as developed at the Instrument Division of LSI for the IBM 1620 digital computer is a modified Stepwise Regression with Simple Learning routine.

A detailed description of the regression program and instructions for its use are given in Appendix E of Volume II.

## 4.5 OPTIMIZATION

Optimization of the system for which the various simulation models have been constructed forms the core of the PRESTO concept. System optimization may be defined as the identification of operational and technical parameter values for the system such that in some sense a maximum return is achieved for a given investment, consistent with certain specified requirements. This process is carried out through manipulation of the mathematical models constructed during the simulation phase of the analysis.

The optimization technique is essentially a steepest descent sequential search technique. A weighting procedure is used in selecting the initial points employed in the search procedure to assure coverage of the area of interest. Provisions have been made to cope with both linear and non-linear objective and constraining models. Several procedures have been included to circumvent the problem of constraint boundaries. The most critical of these procedures is an adaptation of linear programming to ascertain a "non-violating" search direction.

Since the approach to the solution of the optimization problem is non-deterministic, the foremost difficulty in applying the technique is the recognition of the true solution. To overcome this difficulty, the current routine depends both on the complete investigation of the area of interest, and on the generation of many solutions for confidence in obtaining the true solution.

The routine has been implemented on both the IBM 1620 and IBM 7090 computers. A comprehensive review of the optimization routine appears in Appendix F of Volume II of this report.

# 5 PRESTO APPLICATION

The solution to the launch vehicle problem involves the simulation, optimization, and evaluation of the vehicle in terms of such parameters as performance, reliability, and cost. Though the maximization of performance--constrained by reliability and cost specifications--and the maximization of reliability--constrained by performance and cost limitations--are system optimization strategies within the realm of the PRESTO concept, the strategy chosen for the demonstration of the PRESTO methodology in this report is to minimize the cost of a launch vehicle system while maintaining pre-established system performance and reliability specifications.

## 5.1 STUDY LAUNCH VEHICLE SYSTEM*

An hypothetical launch vehicle configuration, similar to the Atlas/Agena spacecraft structure, was formulated as the vehicle to be studied. This Study Launch Vehicle System (SLVS) was selected because:

- The SLVS is believed to be representative of one which may satisfy many future mission requirements.
- The SLVS provides a level of complexity sufficient to demonstrate effectively the utility of the PRESTO concept.
- The extent of available information+ pertaining to the SLVS reduces the number of assumptions required to perform a realistic analysis.

The Study Launch Vehicle System can be briefly described as a two and one-half stage, liquid-fueled missile. The SLVS first stage (BOGY) is based upon the modified Atlas LV-3 vehicle; the SLVS second stage (RAM) has some similarity to the Agena vehicle. An illustration of the basic structure of the SLVS is presented in Figure 5-1.†

* A comprehesive review of the Study Launch Vehicle System is contained in Appendix D of this report.

\+ Postulated data were utilized where security classification prohibited the inclusion of real data.

† Because of the length of the figures of this section, they all are located after the text.

In the SLVS first stage, thirteen subsystems were identified as follows:

- Booster Propulsion
- Booster Pneumatics
- Booster Hydraulics
- Booster Airframe
- Booster Separation
- Sustainer Propulsion
- Sustainer Hydraulics
- Sustainer Airframe
- Sustainer Pneumatics
- Flight Control
- Electrical
- Guidance
- Propellant Utilization.

Four subsystems were identified in the SLVS second stage. These are:

- Airframe
- Propulsion
- Electrical
- Guidance.

The function of each of these subsystems is thoroughly explained in Appendix D, Volume II, of this report.

One of the subsystems, Flight Control, was chosen to be analyzed at subordinate levels. The complete breakdown of the SLVS as presented for PRESTO analysis is shown in Figure 5-2.

## 5.2 UNIFIED CONCEPT VERIFICATION

The mathematical models which describe the performance, reliability, and cost of the Study Launch Vehicle System were to have been generated by the generalized simulation techniques described in Part A, Volume III; Appendix B, Volume II; and Appendix C, Volume II, respectively. However, the inadequacy of operational performance simulation techniques precluded the consideration of performance in the application of PRESTO to the SLVS.

A revised strategy was therefore applied in which the SLVS cost was minimized, though constrained by a reliability specification. It should be noted that the PRESTO concept has not been altered in this respect, but only the degree of demonstration has been reduced. The output from this demonstration is described in Section 5.2.2.2.

### 5.2.1 SLVS Input Data

The input data required by the application of the PRESTO concept to the Study Launch Vehicle System is described in the following sub-sections as they pertain to performance, reliability, economics, and optimization.

#### 5.2.1.1 Performance Simulator Input Data

Although system performance considerations were excluded in the final application of PRESTO to the SLVS, it was decided that, since performance simulations relative to the SLVS were attempted, a discussion of these should be included here.

The simulator which was to have generated the performance model of the SLVS was the Westervelt Simulator.* The input information required by the Westervelt Simulator consists of a Source Program and an Element Descriptor Library.

The Source Program, which is composed of the following:

- System Description,
- Input Parameters,
- Desired Results, and
- New Element Tape,

serves to completely describe the problem under consideration.

*The reader is referred to Part A, Vol III for a comprehensive review of the Westervelt Simulator.

Within the Element Descriptor Library is a collection of descriptive statements completely describing the physical laws which govern the behavior of each of the elements defined by the Source Program.

The source program and element descriptions for two SLVS subsystems were generated and submitted to the Westervelt Simulator for modeling.

These subsystems were:

- Simplified Pneumatics Subsystem
- Modified Sustainer Vehicle.

With the exception of some very basic descriptive information, most of the inputs required by the simulator had to be synthesized. Principles of physics, flight dynamics, and space technology were utilized to develop the descriptions of the elements of the above subsystems.* Numeric data were compiled to satisfy the need created by the "input parameters" of the system, though not all of these would necessarily appear in the output performance model. Although the generation of the information required for the simulation of the above subsystems was done with considerable care and in great detail, it was recognized that some errors or omissions had perhaps been incorporated into the descriptions. However, it seemed that erroneous statement collections could be corrected, as these would be included in the generated model. The recognition of necessary statement collections, which might have been omitted inadvertently, was assumed to be the responsbility of the Simulator.

The results of the performance simulation attempts are discussed in Subsection 5.2.2.1.1.

5.2.1.2 Reliability Simulator Input Data

The collection of data for the reliability simulator is discussed in detail in Appendix D, Volume II, entitled: "Launch Vehicle System." Figure 5-3, which follows, contains the Data Transmittal Forms (DTF's) from which the data required for the reliability simulation of the SLVS were prepared. Appendix B, Volume II, contains the instructions necessary for the utilization of these DTF's. The results of the simulation are discussed in Section 5.2.2.1.2.

*A review of tasks dealing with SLVS performance is contained in Section 3 of Appendix D, Vol. II. The listings of the Source Programs and Element Descriptions of the Simplified Pneumatics Subsystem and Modified Sustainer Vehicle are also given.

5.2.1.3 Economics Simulator Input Data

Available cost data relating to the reliability of components are very sparse. As a result, the cost functions of the elements in the SLVS likely are not representative of the true cost-reliability relationships.

One fact which aided to the development of the element cost functions was that several trends of these functions were known, viz:

- At zero failure rate[3], the cost of a component is infinite.
- The cost of a component decreases as its failure rate increases.
- The cost of a component approaches a minimal cost as its failure rate becomes very large.

A function which reasonably satisfies these trends is given in Figure 5-4. With considerable difficulty, three cost-failure rate data points for each element of the SLVS were obtained; one data point at the "nominal" failure rate, one at the "minimal" failure rate, and the other at the "maximal" failure rate.

An A and B for each element were computed such that the function in Figure 5-4 $\left(COST = \frac{A}{FR^{B}} + C\right)$ satisfied the input data points of that element. Table 5-1 gives these A's, B's, and C's, while Table 5-2 presents the cost/failure rate data.

The formulation of the SLVS economics model could not be accomplished with the Westervelt Simulator because of the internal difficulties of the Simulator. However, since the SLVS economics model is simply the sum of the element cost functions, the system model was hand-generated. The reader is referred to Appendix C, Volume II, for a treatment of economics simulation utilizing the Westervelt Simulator. The economics model is discussed in Section 5.2.2.1.3.

5.2.1.4 Optimization Input Data

Figure 5-5 contains the input data required by the optimization routine. The reader is referred to Appendix F, Volume II, for a thorough treatment of the optimization transmittal forms. Figure 5-6 is a listing of the computer subroutine (FUNCY) in which the objective function (Subroutine ECON, Section 5.2.2.1.3) and the constraining function (Subroutine LUV, Section 5.2.2.1.2) are evaluated.

[3] Failure rate may be defined as the number of failures which occur in a unit time.

### 5.2.2 Results of PRESTO Application to SLVS

The results of the application of the PRESTO concept to the SLVS may be divided into Simulation Results and Optimization Results.

#### 5.2.2.1 Simulation Results

Ideally, the output from the simulation of performance, reliability, and economics would be in the form of stored computer object programs which contain the mathematical models describing these system characteristics. The status of the performance and economics simulators is such that this could not be accomplished in these areas. The reliability simulator, however, does provide the desired output.

| ELEMENT NAME | A | B | C |
|---|---|---|---|
| SLVS 1ST STAGE | | | |
| BOOSTER PROPULSION | .1458E+08 | .2793E+02 | .1246E+07 |
| BOOSTER PNEUMATICS | .2855E+00 | .3610E+01 | .3727E+05 |
| BOOSTER HYDRAULICS | .6678E+21 | .2953E+02 | .5423E+05 |
| BOOSTER AIRFRAME | .3460E-11 | .9062E+01 | .1260E+06 |
| BOOSTER SEPARATION | .1849E+00 | .8303E+01 | .3829E+05 |
| SUSTAINER PROPULSION | .2585E+09 | .3271E+02 | .8313E+06 |
| SUSTAINER HYDRAULICS | .2714E+19 | .3693E+02 | .3615E+05 |
| SUSTAINER AIRFRAME | .5885E-03 | .4320E+01 | .2241E+06 |
| SUSTAINER PNEUMATICS | .8428E-10 | .3464E+02 | .5829E+05 |
| 1ST STG. PROP. UTIL. | .2061E+00 | .2820E+01 | .4692E+05 |
| 1ST STG. ELECTRICAL | .3129E+06 | .2737E+02 | .6969E+05 |
| 1ST STG. GUIDANCE | .1731E-10 | .7520E+01 | .2808E+06 |
| 1ST STG. FLT. CONT. | | | |
| FLT. CONT. CABLING | .2103E-13 | .1120E+02 | .9204E+04 |
| FLT. CONT. EXC. TRAN. | .1872E-17 | .1438E+02 | .1560E+03 |
| FLT. CONT. PROGRAMMER | .5818E-14 | .3253E+02 | .3025E+05 |
| FLT. CONT. AUTOPILOT | | | |
| AUTOPILOT DISPL. GYRO | .4369E+02 | .5318E+02 | .1170E+06 |
| AUTOPILOT SERVO AMPL. | .1229E-10 | .2574E+02 | .1443E+06 |
| AUTOPILOT RATE GYRO | .3318E-16 | .2772E+02 | .1031E+06 |
| SLVS 2ND STAGE | | | |
| 2ND STG. AIRFRAME | .1254E-01 | .2917E+01 | .1595E+06 |
| 2ND STG. PROPULSION | .6555E+00 | .3433E+01 | .9540E+06 |
| 2ND STG. ELECTRICAL | .8022E+01 | .1643E+01 | .3284E+05 |
| 2ND STG. GUID. CONT. | .6919E-02 | .2190E+02 | .4175E+06 |

ELEMENT COST COEFFICIENTS
TABLE 5-1

| ELEMENT NAME | FAILURE RATE MAXIMUM | COST | FAILURE RATE NOMINAL | COST | FAILURE RATE MINIMUM | COST |
|---|---|---|---|---|---|---|
| SLVS 1ST STAGE | | | | | | |
| BOOSTER PROPULSION | 195892. | 1246968. | 109201. | 2493936. | 106311. | 3884932. |
| BOOSTER PNEUMATICS | 22669. | 37270. | 3828. | 74541. | 3200. | 108444. |
| BOOSTER HYDRAULICS | 469539. | 54234. | 350567. | 108468. | 346602. | 130123. |
| BOOSTER AIRFRAME | 6117. | 126063. | 1488. | 252126. | 1334. | 465371. |
| BOOSTER SEPARATION | 64768. | 38295. | 22897. | 76590. | 21501. | 102860. |
| SUSTAINER PROPULSION | 215429. | 831312. | 119176. | 1662624. | 115967. | 2861876. |
| SUSTAINER HYDRAULICS | 367246. | 36156. | 237520. | 72312. | 233195. | 107431. |
| SUSTAINER AIRFRAME | 4890. | 224112. | 1033. | 448224. | 905. | 621032. |
| SUSTAINER PNEUMATICS | 81550. | 58294. | 37294. | 116589. | 35819. | 294219. |
| 1ST STG. PROP. UTIL. | 8568. | 45920. | 1261. | 93840. | 1017. | 132977. |
| 1ST STG. ELECTRICAL | 175932. | 69690. | 105640. | 139380. | 103297. | 198462. |
| 1ST STG. GUIDANCE | 3873. | 280830. | 699. | 561660. | 594. | 1235936. |
| 1ST STG. FLT. CONT. | | | | | | |
| FLT. CONT. CABLING | 18856. | 9204. | 2663. | 18409. | 2457. | 31890. |
| FLT. CONT. EXC. TRAN. | 11820. | 156. | 4119. | 312. | 3862. | 550. |
| FLT. CONT. PROGRAMMER | 41166. | 30259. | 26596. | 60518. | 25943. | 98203. |
| FLT. CONT. AUTOPILOT | | | | | | |
| AUTOPILOT DISPL. GYRO | 121440. | 117031. | 86207. | 234062. | 85032. | 359840. |
| AUTOPILOT SERVO AMPL. | 42247. | 144374. | 23753. | 288749. | 23137. | 428320. |
| AUTOPILOT RATE GYRO | 32322. | 103177. | 16779. | 206354. | 16260. | 349720. |
| SLVS 2ND STAGE | | | | | | |
| 2ND STG. AIRFRAME | 1882. | 159528. | 367. | 319056. | 266. | 567485. |
| 2ND STG. PROPULSION | 7617. | 954040. | 1604. | 1908080. | 1203. | 3516037. |
| 2ND STG. ELECTRICAL | 5916. | 32844. | 635. | 65688. | 283. | 156855. |
| 2ND STG. GUID. CONT. | 68022. | 417588. | 44131. | 835176. | 42539. | 1351313. |

COST FAILURE RATE DATA
TABLE 5-2

#### 5.2.2.1.1 Performance Model

The Westervelt Simulator was unable to generate realistic performance models of the SLVS subsystems presented to it. It is felt that the failure of these simulation attempts may be attributed to the following:

a. The inability of the Simulator to model adequately systems containing switches or switch-like elements;

b. The generation of trivial solutions in the utilization of the estimate capability* in the output model;

c. The inability of the Simulator to ascertain a fulty Element Descriptor Library;

d. Programming errors in the program which decodes stored information into an algorithm in MAD (Michigan Algorithm Decoder) language.

A. Simplified Pneumatics Subsystem

Several unsuccessful attempts to simulate the performance of the Simplified Pneumatics Subsystem were made. After careful and exhaustive analysis of the initial attempted simulations, it was determined that certain statement collections required for simulation were omitted.** Although the required statement collections were incorporated into the element descriptions of the Simplified Pneumatics Subsystem, subsequent attempted simulations yielded only trivial solutions. (See Section 4).

The algorithms in which the trivial solutions appeared were not machine-generated MAD statements, but were manually decoded*** with considerable difficulty from information in a "dump" of core storage. Additional performance simulations of the Simplified Pneumatics Subsystem were attempted. However, no legitimate models were obtained.

*See Section 3.1.5.2, Part A, Vol. III.

**In view of the difficulty involved in the manual location of omissions of this type, it was suggested that the Simulator incorporate the facility to indicate Element Description Library deficiencies.

***This problem can be attributed to programming errors in the output program of the Simulator.

B. Modified Sustainer Vehicle

Several unsuccessful attempts to simulate the performance of the Modified Sustainer Vehicle were made. It is felt that the difficulties cited above were also responsible for the failure to model the performance of the Modified Sustainer Vehicle.

5.2.2.1.2 Reliability Model

The output from the Reliability Simulator is in the form of five computer programs in the MAD language which have been automatically generated.

Each element in the SLVS PRESTO Analysis Breakdown, in Figure 5-2, which is comprised of elements at a lower functional level in the system was modeled by the simulator, and a subroutine having the element name was generated. The reliability model for the SLVS is "nested" in the five subroutines in the form of statements which collectively evaluate the probability of failure for the element with the subroutine name. Pages 29 through 33 of Figure 5-7 give the generated subroutines.

The "LUV" subroutine calls upon two subroutines, "BOGY" and "RAM", which are the models for the first and second stages of the Study Launch Vehicle System, respectively. The BOGY subroutine (page 30 of Figure 5-7) calls upon a library program PEXP to compute the element mode probabilities from the exponential function for twelve of the first stage elements. In addition, the subroutine FLTCON is called by BOGY, since the Flight Control is composed of lower-level elements in the system.

By comparing Figure 5-2 with page 31 of Figure 5-7, it can be seen why FLTCON utilizes PEXP for three of the elements comprising the flight control and also calls upon the subroutine AUTOPI. The AUTOPI subroutine requires only the exponential function to evaluate the autopilot element mode probabilities.

The final page of Figure 5-7 presents the second stage subroutine, RAM. All elements of this stage are modeled using the exponential function.

A single statement in the MAD Language is used to effect the evaluation of the LUV probability of failure. This statement is as follows:

EXECUTIVE LUV. (PFAIL).

The probability of the successful SLVS mission is

1 - PFAIL.

5.2.2.1.3 Economics Model

It was pointed out in Section 5.2.1.3 of this volume of the final report that the economics model for the system involves a summation of the element costs. These element costs are determined from the function given in Figure 5-4.

To effect compatibility with the concept of exercising a reliability and an economics model for the SLVS during the optimization procedure, a model for economics was written in the from of a computer subroutine. This is given on page 28 of Figure 5-7. If an economics simulator had been employed in this Unified Concept Verification, the simulator output would be required to be in a similar form.

Referring to Page 28 of Figure 5-7, the statement labeled "Q2" determines system cost by substituting the set of element cost parameters ($A_i$, $B_i$, and $C_i$) into the equation for each element and summing the individual results. The $C_i$ cost parameter is called $CONN_i$ in this subroutine.

5.2.2.2 Optimization Results

The demonstration of the applicability of PRESTO to a launch vehicle was effected by the completion of two tasks utilizing the I. B. M. 7090 computer and the simulation and optimization techniques developed for the PRESTO methodology.

- Task 1 involves the minimization of SLVS cost, constrained by a system reliability limitation (lower).
- Task 2 consists of a series of minimization of SLVS cost, constrained by a family of reliability limits.

The inputs and outputs of the simulation phase remain unchanged in the execution of the above tasks. These have been discussed in previous sections. However, changes in the optimization input data are required for completion of each of the above tasks.

Task 1

Task 1 is intended to show the power of PRESTO as a tool in system design. As an illustration of this capability the following problem was posed and solved.

> Given the SLVS and associated data appearing in Appendix D, Vol. II, determine the required component reliabilities which yield a minimal vehicle cost, while satisfying the system constraint that the reliability of the system be at least 80 percent.

Systematic evaluations of the SLVS Economics and Reliability models, discussed in Sections 5.2.2.1.3 and 5.2.2.1.2, within the Optimization Routine (Appendix F, Vol. II) ultimately led to the optimal system* presented in Figure 5-7. Page 1 of Figure 5-7 is a summary of key system information.

The summary page describes the mission requirements of time and reliability, and presents the results of the application of PRESTO on both the system and element levels. The indentation of element names is indicative of the functional level at which the element exists in the system. Additional pages of Figure 5-7 contain element information. These element summary pages include such background information as the cost function describing the element in terms of its failure rate, the realizable range of the element failure rate, and the applicable environmental factors corresponding to time increments within the mission. The resulting optimized element information is also found on the element summary pages.

Figure 5-8 is a similar system summary listing of cost and reliability information computed for the SLVS at nominal element failure rates before the employment of an optimization technique. Note that the summary of Figure 5-8 is similar to Figure 5-7 with the following exceptions:

(1) there is no reliability requirement;

(2) the cost of the SLVS for 88.31 percent reliability is not optimal.

*The optimal SLVS is accurate insofar as the data of Appendix D, Vol. II are accurate.

A comparison of the optimal SLVS summary (Figure 5-7) with the summary of the nominal SLVS (Figure 5-8) yields two conclusions:

(1) Over $5,000,000 could be saved for the specified mission by the application of the PRESTO concept, and

(2) the SLVS reliability at nominal conditions was much greater than required by the mission.

By generalizing this specific case, it becomes quite obvious that PRESTO could be utilized very advantageously by the systems designer to (1) assist in the allocation of reliabilities to subsystems, components, etc. and (2) eliminate over-design of the system in the reliability area.

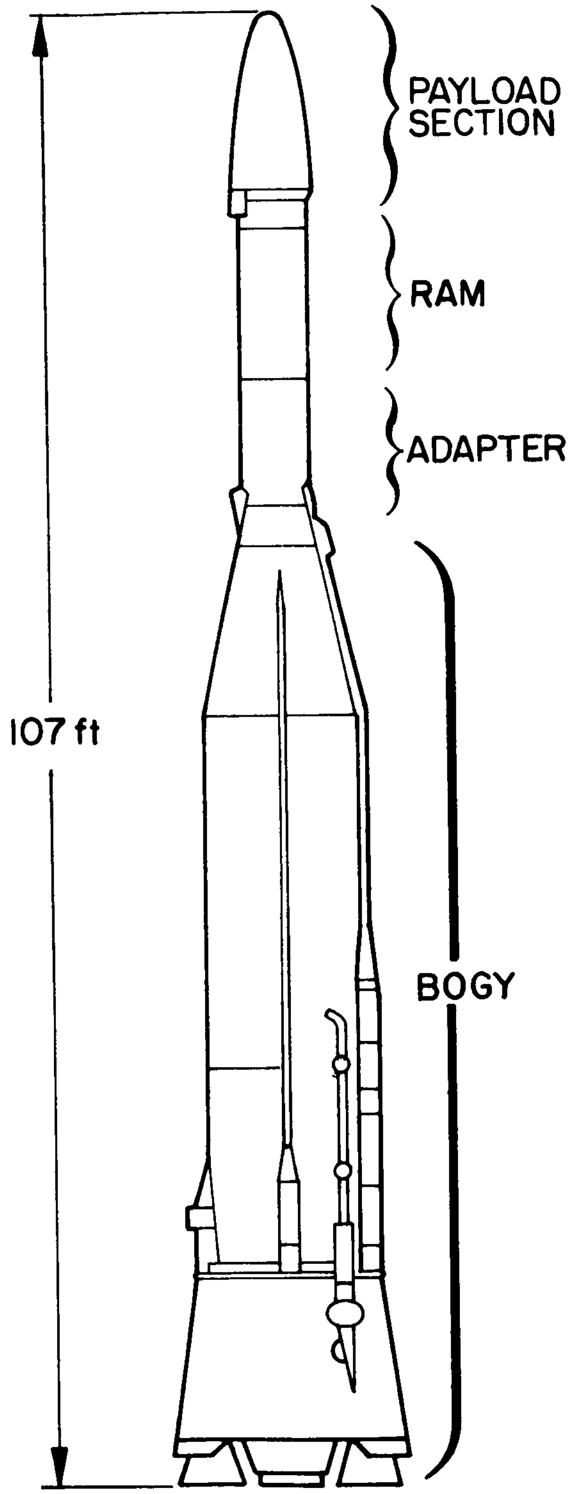
Task 2

The nature of Task 2 is such that it demonstrates the utility of PRESTO as a management decision-making tool. The philosophy assumed by Task 2 is to determine repeatedly the optimal system as in Task 1, but with a reduced reliability constraint at each cycle.

Figure 5-9 shows the plotted results* of this strategy. From a plot such as the SLVS Cost vs. Reliability illustration of Figure 5-9, an objective basis could be provided for the selection of the system reliability which yields the maximum reliability per dollar value. This philosophy could be extended or applied immediately by NASA management as a decision-making tool.

Through the application of PRESTO has been demonstrated, to a reduced degree, it is felt that its development is still in its infancy. Only one's imagination can conceive the added power of this tool with the inclusion of performance into its scope.

*The .89 SLVS reliability point does not appear on the plot. The optimized SLVS cost for this point is $14,096,430.




STAGE

1ST stage-LOX/RP-1 (BOGY)

2ND stage-IRNFA/UDMH (RAM)

MISSION CAPABILITY

300 n. mi. orbit- 800 lbs

Lunar orbit - 80 lbs

Planitary probe - 50 lbs

USE

Lunar probes

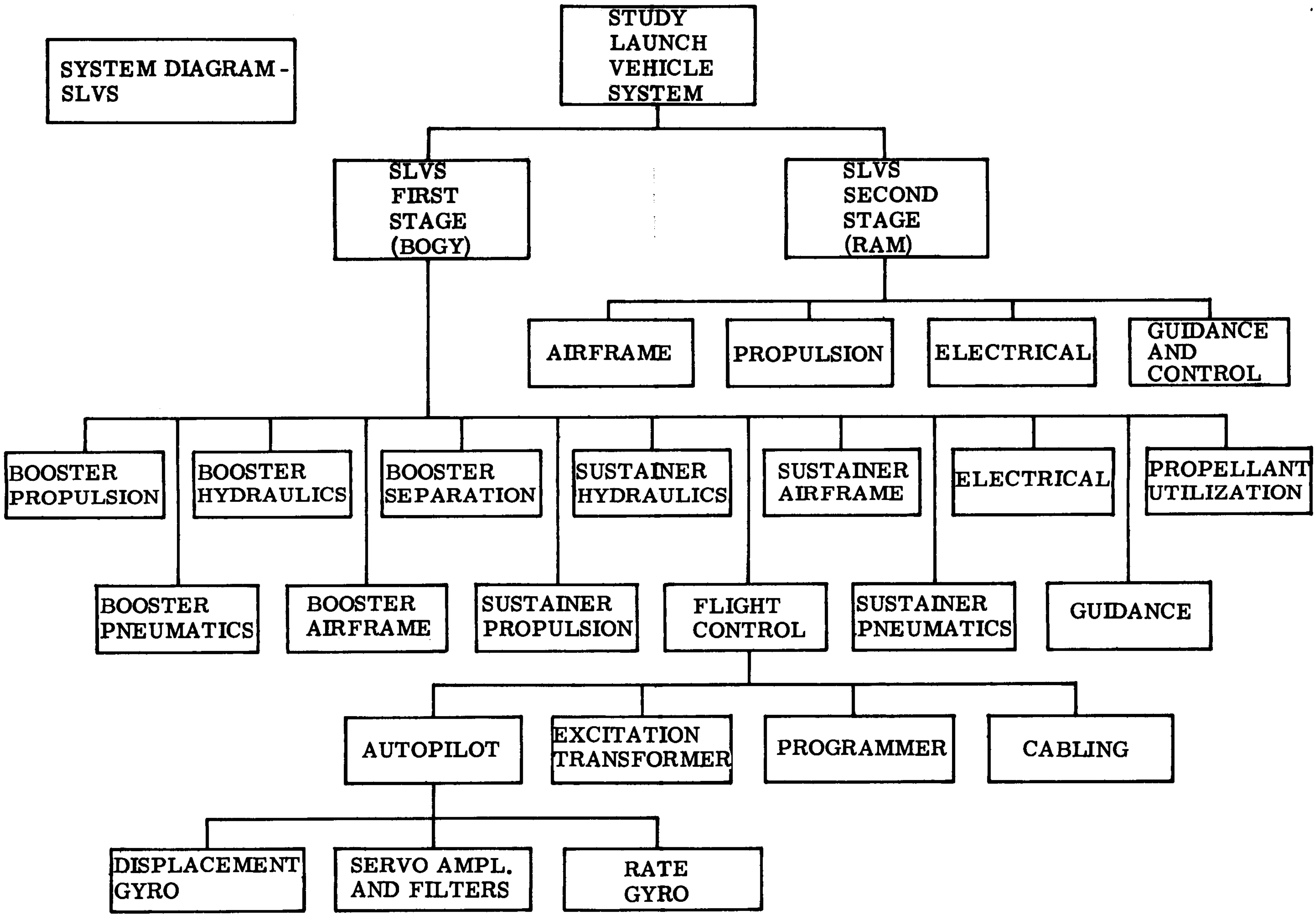
Communications satellites

Scientific satellites

LAUNCH RATE CAPABILITY

10/yr/pad

BASIC STRUCTURE OF STUDY LAUNCH VEHICLE SYSTEM (SLVS)
FIGURE 5-1




SLVS BREAKDOWN FOR PRESTO ANALYSIS
FIGURE 5-2

| LEAR SIEGLER, INC. INSTRUMENT DIVISION | RAPID DTFI | PROBABILISTIC SYSTEM MODE ANALYSIS | SHEET 1 of 28 |
|---|---|---|---|

### TITLE CARD I

| CODE | SN | SYSTEM NAME | DATE | 80 |
|---|---|---|---|---|
| LUV | 1 | LAUNCH VEHICLE | 9 14 65 | 1 |

### TITLE CARD 2

| H | MODE NAME | 80 |
|---|---|---|
| 1 | FAILURE | 2 |

### SYSTEM DEFINITION CARD

| NE | ELEMENT NUMBER | 80 |
|---|---|---|
| 2 | 1 1 | 3 |

### TIME CARDS

| NT | TIME | J | TIME | J | TIME | J | TIME | J | TIME | J | 80 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 0.0 | 0 | .0375 | 0 | .3778 | 0 | .03833 | 0 | .07347 | | 4 |
| | .07772 | 0 | .07839 | 0 | .08951 | 0 | .09222 | 0 | .12476 | | 4 |
| | | | | | | | | | | | 4 |
| | | | | | | | | | | | 4 |
| | | | | | | | | | | | 4 |

SLVS RELIABILITY SIMULATION DATA (Sheet 1 of 28)
FIGURE 5-3

LEAR SIEGLER, INC.
INSTRUMENT DIVISION

RAPID
DTF II

PROBABILISTIC SYSTEM MODE ANALYSIS

SHEET 2 of 28

## SYSTEM MODE ARRAY CARDS

| NS | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 80 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 |
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SLVS RELIABILITY SIMULATION DATA (Sheet 2 of 28)

FIGURE 5-3

| LEAR SIEGLER, INC. INSTRUMENT DIVISION | RAPID DTF III | PROBABILISTIC SYSTEM MODE ANALYSIS | SHEET 3 of 28 |
|---|---|---|---|

## ELEMENT CARDS

| EN | NAME | S | LAMBDA | CODE | 80 |
|---|---|---|---|---|---|
| 1 | BOGY | O | | BOGY | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | 80 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

| EN | NAME | S | LAMBDA | CODE | 80 |
|---|---|---|---|---|---|
| 2 | SECOND STG | O | | RAM | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | 80 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

| EN | NAME | S | LAMBDA | CODE | 80 |
|---|---|---|---|---|---|
| | | | | | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | 80 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

SLVS RELIABILITY SIMULATION DATA (Sheet 3 of 28)
FIGURE 5-3

## ELEMENT K FACTOR CARDS

| EB (1-3) | EE (6-7) | K FACTOR (10-19) | K FACTOR (24-33) | K FACTOR (38-47) | K FACTOR (52-61) | K FACTOR (66-75) | 80 |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 1. | 1. | 1. | 1. | 1. | 7 |
| | | 1. | 1. | 1. | 1. | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |

| EB (1-3) | EE (6-7) | K FACTOR (10-19) | K FACTOR (24-33) | K FACTOR (38-47) | K FACTOR (52-61) | K FACTOR (66-75) | 80 |
|---|---|---|---|---|---|---|---|
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
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| EB (1-3) | EE (6-7) | K FACTOR (10-19) | K FACTOR (24-33) | K FACTOR (38-47) | K FACTOR (52-61) | K FACTOR (66-75) | 80 |
|---|---|---|---|---|---|---|---|
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |

FIGURE 5-3 SLVS RELIABILITY SIMULATION DATA (Sheet 4 of 28)

| LEAR SIEGLER, INC. INSTRUMENT DIVISION | RAPID DTFI | PROBABILISTIC SYSTEM MODE ANALYSIS | SHEET ___ of ___ |
|---|---|---|---|

## TITLE CARD I

| CODE (cols 4–10) | SN (col 12) | SYSTEM NAME (cols 18–63) | DATE (cols 71–77) | Col 80 |
|---|---|---|---|---|
| BOGY | 2 | STUDY LAUNCH VEHICLE SYSTEM - FIRST STAGE | 9 14 65 | 1 |

## TITLE CARD 2

| M (col 3) | MODE NAME (cols 18–63) | Col 80 |
|---|---|---|
| 1 | FAILURE | 2 |

## SYSTEM DEFINITION CARD

| NE (cols 1–3) | ELEMENT NUMBER 1–50 (cols 21–70) | Col 80 |
|---|---|---|
| 13 | 1111111111111 | 3 |

## TIME CARDS

| NT | TIME | J | TIME | J | TIME | J | TIME | J | TIME | J | Col 80 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 0.0 | 0 | .0375 | 0 | .03778 | 0 | .03833 | 0 | .07347 | 0 | 4 |
| | .07772 | 0 | .07839 | 0 | .08951 | 0 | .09222 | 0 | .12476 | | 4 |
| | | | | | | | | | | | 4 |
| | | | | | | | | | | | 4 |
| | | | | | | | | | | | 4 |

FIGURE 5-3 SLVS RELIABILITY SIMULATION DATA (Sheet 5 of 28)

## SYSTEM MODE ARRAY CARDS

| NS (cols 1–3) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | col 80 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 |
| | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 |
| | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 |
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SLVS RELIABILITY SIMULATION DATA (Sheet 6 of 28)

FIGURE 5-3

| LEAR SIEGLER, INC. INSTRUMENT DIVISION | RAPID DTF III | PROBABILISTIC SYSTEM MODE ANALYSIS | SHEET 7 of 28 |
|---|---|---|---|

## ELEMENT CARDS

| EN | NAME | S | LAMBDA | CODE | |
|---|---|---|---|---|---|
| 1 | BSTR PROPU | 1 | 109201. | 2360 | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE 1 | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

| EN | NAME | S | LAMBDA | CODE | |
|---|---|---|---|---|---|
| 2 | BSTR PNEUM | 1 | 3828. | 2612 | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE 1 | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

| EN | NAME | S | LAMBDA | CODE | |
|---|---|---|---|---|---|
| 3 | BSTR HYDRA | 1 | 350567. | 2621 | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

SLVS RELIABILITY SIMULATION DATA (Sheet 7 of 28)
FIGURE 5-3

| LEAR SIEGLER, INC. INSTRUMENT DIVISION | RAPID DTF III | PROBABILISTIC SYSTEM MODE ANALYSIS | SHEET 8 of 28 |
|---|---|---|---|

ELEMENT CARDS

| EN | NAME | S | LAMBDA | CODE | |
|---|---|---|---|---|---|
| 4 | BSTR AFME | 1 | 1488. | 2020 | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE 1 | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

| EN | NAME | S | LAMBDA | CODE | |
|---|---|---|---|---|---|
| 5 | BSTR SEPAR | 1 | 22897. | 2400 | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

| EN | NAME | S | LAMBDA | CODE | |
|---|---|---|---|---|---|
| 6 | SUST PROPU | 1 | 119176. | 2350 | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE 1 | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

SLVS RELIABILITY SIMULATION DATA (Sheet 8 of 28)
FIGURE 5-3

| LEAR SIEGLER, INC. INSTRUMENT DIVISION | RAPID DTF III | PROBABILISTIC SYSTEM MODE ANALYSIS | SHEET 9 of 28 |
|---|---|---|---|

## ELEMENT CARDS

| EN | NAME | S | LAMBDA | CODE | |
|---|---|---|---|---|---|
| 7 | SUST HYDRA | 1 | 237520. | 2622 | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE 1 | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

| EN | NAME | S | LAMBDA | CODE | |
|---|---|---|---|---|---|
| 8 | SUST AFME | 1 | 1033. | 2010 | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE 1 | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

| EN | NAME | S | LAMBDA | CODE | |
|---|---|---|---|---|---|
| 9 | SUST PNEUM | 1 | 37294. | 2611 | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE 1 | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

SLVS RELIABILITY SIMULATION DATA (Sheet 9 of 28)
FIGURE 5-3

| LEAR SIEGLER, INC. INSTRUMENT DIVISION | RAPID DTF III | PROBABILISTIC SYSTEM MODE ANALYSIS | SHEET 10 of 28 |
|---|---|---|---|

## ELEMENT CARDS

| EN | NAME | S | LAMBDA | CODE | |
|---|---|---|---|---|---|
| 10 | PROP UTILI | 1 | 1261. | 2700 | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE 1 | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

| EN | NAME | S | LAMBDA | CODE | |
|---|---|---|---|---|---|
| 11 | ELECTRICAL | 1 | 105640. | 2500 | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE 1 | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

| EN | NAME | S | LAMBDA | CODE | |
|---|---|---|---|---|---|
| 12 | GUIDANCE | 1 | 699. | 2200 | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE 1 | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

SLVS RELIABILITY SIMULATION DATA (Sheet 10 of 28)
FIGURE 5-3

| LEAR SIEGLER, INC. INSTRUMENT DIVISION | RAPID DTF III | PROBABILISTIC SYSTEM MODE ANALYSIS | SHEET 11 of 28 |
|---|---|---|---|

ELEMENT CARDS

| EN | NAME | S | LAMBDA | CODE | |
|---|---|---|---|---|---|
| 13 | FLT CONTRL | 0 | | FLTCON | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

| EN | NAME | S | LAMBDA | CODE | |
|---|---|---|---|---|---|
| | | | | | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

| EN | NAME | S | LAMBDA | CODE | |
|---|---|---|---|---|---|
| | | | | | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

SLVS RELIABILITY SIMULATION DATA (Sheet 11 of 28)
FIGURE 5-3

## ELEMENT K FACTOR CARDS

| EB | EE | K FACTOR | K FACTOR | K FACTOR | K FACTOR | K FACTOR | 80 |
|---|---|---|---|---|---|---|---|
| 1 | 3 | 1. | 1. | 0. | 0. | 0. | 7 |
| | | 0. | 0. | 0. | 0. | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |

| EB | EE | K FACTOR | K FACTOR | K FACTOR | K FACTOR | K FACTOR | 80 |
|---|---|---|---|---|---|---|---|
| 4 | 5 | 1. | 1. | 1. | 0. | 0. | 7 |
| | | 0. | 0. | 0. | 0. | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |

| EB | EE | K FACTOR | K FACTOR | K FACTOR | K FACTOR | K FACTOR | 80 |
|---|---|---|---|---|---|---|---|
| 6 | 7 | 1. | 1. | 1. | 1. | 1. | 7 |
| | | 0. | 0. | 0. | 0. | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |

FIGURE 5-3 SLVS RELIABILITY SIMULATION DATA (Sheet 12 of 28)

| LEAR SIEGLER, INC. INSTRUMENT DIVISION | RAPID DTF III A | PROBABILISTIC SYSTEM MODE ANALYSIS | SHEET 13 of 28 |
|---|---|---|---|

## ELEMENT K FACTOR CARDS

| EB | EE | K FACTOR | K FACTOR | K FACTOR | K FACTOR | K FACTOR | 80 |
|---|---|---|---|---|---|---|---|
| 8 | 9 | 1. | 1. | 1. | 1. | 1. | 7 |
| | | 1. | 0. | 0. | 0. | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |

| EB | EE | K FACTOR | K FACTOR | K FACTOR | K FACTOR | K FACTOR | 80 |
|---|---|---|---|---|---|---|---|
| 10 | 10 | 1. | 1. | 1. | 1. | 0. | 7 |
| | | 0. | 0. | 0. | 0. | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |

| EB | EE | K FACTOR | K FACTOR | K FACTOR | K FACTOR | K FACTOR | 80 |
|---|---|---|---|---|---|---|---|
| 11 | 11 | 1. | 1. | 1. | 1. | 1. | 7 |
| | | 1. | 0. | 0. | 0. | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |

FIGURE 5-3 SLVS RELIABILITY SIMULATION DATA (Sheet 13 of 28)

## ELEMENT K FACTOR CARDS

| EB (1-3) | EE (5-7) | K FACTOR (10-19) | K FACTOR (24-33) | K FACTOR (38-47) | K FACTOR (52-61) | K FACTOR (66-75) | 80 |
|---|---|---|---|---|---|---|---|
| 13 | 13 | 0. | 0. | 1. | 1. | 1. | 7 |
| | | 1. | 1. | 1. | 1. | 1. | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |

| EB (1-3) | EE (5-7) | K FACTOR (10-19) | K FACTOR (24-33) | K FACTOR (38-47) | K FACTOR (52-61) | K FACTOR (66-75) | 80 |
|---|---|---|---|---|---|---|---|
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |

| EB (1-3) | EE (5-7) | K FACTOR (10-19) | K FACTOR (24-33) | K FACTOR (38-47) | K FACTOR (52-61) | K FACTOR (66-75) | 80 |
|---|---|---|---|---|---|---|---|
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |

FIGURE 5-3 SLVS RELIABILITY SIMULATION DATA (Sheet 14 of 28)

| LEAR SIEGLER, INC. INSTRUMENT DIVISION | RAPID DTFI | PROBABILISTIC SYSTEM MODE ANALYSIS | SHEET 15 of 28 |
|---|---|---|---|

### TITLE CARD I

| CODE | SN | SYSTEM NAME | DATE | |
|---|---|---|---|---|
| FLTCON | 3 | FLIGHT CONTROL | 9 14 65 | 1 |

### TITLE CARD 2

| H | MODE NAME | |
|---|---|---|
| 1 | FAILURE | 2 |

### SYSTEM DEFINITION CARD

| NE | ELEMENT NUMBER | |
|---|---|---|
| 4 | 1111 | 3 |

### TIME CARDS

| NT | TIME | J | TIME | J | TIME | J | TIME | J | TIME | J | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 0. | 0 | .0375 | 0 | .03778 | 0 | .03833 | 0 | .07347 | 0 | 4 |
| | .07772 | 0 | .07839 | 0 | .08951 | 0 | .09222 | 0 | .12476 | | 4 |
| | | | | | | | | | | | 4 |
| | | | | | | | | | | | 4 |
| | | | | | | | | | | | 4 |

SLVS RELIABILITY SIMULATION DATA (Sheet 15 of 28)
FIGURE 5-3

| LEAR SIEGLER, INC. INSTRUMENT DIVISION | RAPID DTF II | PROBABILISTIC SYSTEM MODE ANALYSIS | SHEET 16 of 28 |
|---|---|---|---|

## SYSTEM MODE ARRAY CARDS

| NS (1–3) | ELEMENT NUMBER 1 (21) | 2 (22) | 3 (23) | 4 (24) | 80 |
|---|---|---|---|---|---|
| 4 | 1 | | | | 5 |
| | | 1 | | | 5 |
| | | | 1 | | 5 |
| | | | | 1 | 5 |
| | | | | | 5 |
| | | | | | 5 |
| | | | | | 5 |
| | | | | | 5 |
| | | | | | 5 |
| | | | | | 5 |
| | | | | | 5 |
| | | | | | 5 |
| | | | | | 5 |
| | | | | | 5 |
| | | | | | 5 |
| | | | | | 5 |
| | | | | | 5 |
| | | | | | 5 |
| | | | | | 5 |
| | | | | | 5 |

SLVS RELIABILITY SIMULATION DATA (Sheet 16 of 28)

FIGURE 5-3

| LEAR SIEGLER, INC. INSTRUMENT DIVISION | RAPID DTF III | PROBABILISTIC SYSTEM MODE ANALYSIS | SHEET 17 of 28 |
|---|---|---|---|

ELEMENT CARDS

| EN | NAME | S | LAMBDA | CODE | |
|---|---|---|---|---|---|
| 1 | CABLING | 1 | 2663. | 2140 | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE 1 | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

| EN | NAME | S | LAMBDA | CODE | |
|---|---|---|---|---|---|
| 2 | EXIT TRANS | 1 | 4119. | 2130 | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE 1 | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

| EN | NAME | S | LAMBDA | CODE | |
|---|---|---|---|---|---|
| 3 | PROGRAMMER | 1 | 26596. | 2110 | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE 1 | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

SLVS RELIABILITY SIMULATION DATA (Sheet 17 of 28)
FIGURE 5-3

| | | | |
|---|---|---|---|
| LEAR SIEGLER, INC. INSTRUMENT DIVISION | RAPID DTF III | PROBABILISTIC SYSTEM MODE ANALYSIS | SHEET 18 of 28 |

ELEMENT CARDS

| EN | NAME | S | LAMBDA | CODE | |
|---|---|---|---|---|---|
| 4 | AUTOPI LOT | 0 | | AUTOPI | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAI LURE | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

| EN | NAME | S | LAMBDA | CODE | |
|---|---|---|---|---|---|
| | | | | | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

| EN | NAME | S | LAMBDA | CODE | |
|---|---|---|---|---|---|
| | | | | | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

SLVS RELIABILITY SIMULATION DATA (Sheet 18 of 28)
FIGURE 5-3

## ELEMENT K FACTOR CARDS

| EB | EE | K FACTOR | K FACTOR | K FACTOR | K FACTOR | K FACTOR | 80 |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 1. | 1. | 1. | 1. | 1. | 7 |
| | | 1. | 0. | 0. | 0. | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |

| EB | EE | K FACTOR | K FACTOR | K FACTOR | K FACTOR | K FACTOR | 80 |
|---|---|---|---|---|---|---|---|
| 2 | 2 | 1. | 1. | 1. | 1. | 1. | 7 |
| | | 0. | 0. | 0. | 0. | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |

| EB | EE | K FACTOR | K FACTOR | K FACTOR | K FACTOR | K FACTOR | 80 |
|---|---|---|---|---|---|---|---|
| 3 | 4 | 1. | 1. | 1. | 1. | 1. | 7 |
| | | 1. | 0. | 0. | 0. | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |

FIGURE 5-3 SLVS RELIABILITY SIMULATION DATA (Sheet 19 of 28)

| LEAR SIEGLER, INC. INSTRUMENT DIVISION | RAPID DTFI | PROBABILISTIC SYSTEM MODE ANALYSIS | SHEET 20 of 28 |
|---|---|---|---|

### TITLE CARD 1

| CODE | SN | SYSTEM NAME | DATE | |
|---|---|---|---|---|
| AUTOPI | 4 | AUTOPILOT | 9 14 65 | 1 |

### TITLE CARD 2

| H | MODE NAME | |
|---|---|---|
| 1 | FAILURE | 2 |

### SYSTEM DEFINITION CARD

| NE | ELEMENT NUMBER | |
|---|---|---|
| 3 | 111 | 3 |

### TIME CARDS

| NT | TIME | J | TIME | J | TIME | J | TIME | J | TIME | J | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 0. | 0 | .0375 | 0 | .03778 | 0 | .03833 | 0 | .07347 | 0 | 4 |
| | .07772 | 0 | .07839 | 0 | .08951 | 0 | .09222 | 0 | .12476 | | 4 |
| | | | | | | | | | | | 4 |
| | | | | | | | | | | | 4 |
| | | | | | | | | | | | 4 |

FIGURE 5-3 SLVS RELIABILITY SIMULATION DATA (Sheet 20 of 28)

| LEAR SIEGLER, INC. INSTRUMENT DIVISION | RAPID DTF II | PROBABILISTIC SYSTEM MODE ANALYSIS | SHEET 21 of 28 |
|---|---|---|---|

## SYSTEM MODE ARRAY CARDS

| NS | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 80 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 |
| | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 |
| | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 |

SLVS RELIABILITY SIMULATION DATA (Sheet 21 of 28)
FIGURE 5-3

ELEMENT CARDS

| EN | NAME | S | LAMBDA | CODE | |
|---|---|---|---|---|---|
| 1 | DISPL GYRO | 1 | 86207. | 2122 | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE 1 | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

| EN | NAME | S | LAMBDA | CODE | |
|---|---|---|---|---|---|
| 2 | SERVO AMPL | 1 | 23753. | 2123 | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE 1 | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

| EN | NAME | S | LAMBDA | CODE | |
|---|---|---|---|---|---|
| 3 | RATE GYRO | 1 | 16779. | 2124 | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE 1 | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

FIGURE 5-3 SLVS RELIABILITY SIMULATION DATA (Sheet 22 of 28)

## ELEMENT K FACTOR CARDS

| EB (1-4) | EE (5-9) | K FACTOR (10-19) | K FACTOR (24-33) | K FACTOR (38-47) | K FACTOR (52-61) | K FACTOR (66-75) | 80 |
|---|---|---|---|---|---|---|---|
| 1 | 3 | 1. | 1. | 1. | 1. | 1. | 7 |
| | | 0. | 0. | 0. | 0. | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |

| EB (1-4) | EE (5-9) | K FACTOR (10-19) | K FACTOR (24-33) | K FACTOR (38-47) | K FACTOR (52-61) | K FACTOR (66-75) | 80 |
|---|---|---|---|---|---|---|---|
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |

| EB (1-4) | EE (5-9) | K FACTOR (10-19) | K FACTOR (24-33) | K FACTOR (38-47) | K FACTOR (52-61) | K FACTOR (66-75) | 80 |
|---|---|---|---|---|---|---|---|
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |

FIGURE 5-3 SLVS RELIABILITY SIMULATION DATA (Sheet 23 of 28)

| LEAR SIEGLER, INC. INSTRUMENT DIVISION | RAPID DTFI | | PROBABILISTIC SYSTEM MODE ANALYSIS | SHEET 24 of 28 |
|---|---|---|---|---|

## TITLE CARD 1

| CODE | SN | SYSTEM NAME | DATE | Col. 80 |
|---|---|---|---|---|
| RAM | 5 | STUDY LAUNCH VEHICLE SYSTEM - SECOND STAGE | 9 14 65 | 1 |

## TITLE CARD 2

| H | MODE NAME | Col. 80 |
|---|---|---|
| 1 | FAILURE | 2 |

## SYSTEM DEFINITION CARD

| NE | ELEMENT NUMBER | Col. 80 |
|---|---|---|
| 4 | 1111 | 3 |

## TIME CARDS

| NT | TIME | J | TIME | J | TIME | J | TIME | J | TIME | J | Col. 80 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 0. | 0 | .0375 | 0 | .03778 | 0 | .03833 | 0 | .07347 | 0 | 4 |
| | .07772 | 0 | .07839 | 0 | .08951 | 0 | .09222 | 0 | .12476 | | 4 |
| | | | | | | | | | | | 4 |
| | | | | | | | | | | | 4 |
| | | | | | | | | | | | 4 |

FIGURE 5-3 SLVS RELIABILITY SIMULATION DATA (Sheet 24 of 28)

## SYSTEM MODE ARRAY CARDS

| NS (cols 1–3) | Cols 4–20 | Element 1 (col 21) | Element 2 (col 22) | Element 3 (col 23) | Element 4 (col 24) | Elements 5–50 (cols 25–70) | Cols 71–79 | Col 80 |
|---|---|---|---|---|---|---|---|---|
| 4 | | 1 | | | | | | 5 |
| | | | 1 | | | | | 5 |
| | | | | 1 | | | | 5 |
| | | | | | 1 | | | 5 |
| | | | | | | | | 5 |
| | | | | | | | | 5 |
| | | | | | | | | 5 |
| | | | | | | | | 5 |
| | | | | | | | | 5 |
| | | | | | | | | 5 |
| | | | | | | | | 5 |
| | | | | | | | | 5 |
| | | | | | | | | 5 |
| | | | | | | | | 5 |
| | | | | | | | | 5 |
| | | | | | | | | 5 |
| | | | | | | | | 5 |
| | | | | | | | | 5 |
| | | | | | | | | 5 |
| | | | | | | | | 5 |

SLVS RELIABILITY SIMULATION DATA (Sheet 25 of 28)

FIGURE 5-3

| LEAR SIEGLER, INC. INSTRUMENT DIVISION | RAPID DTF III | PROBABILISTIC SYSTEM MODE ANALYSIS | SHEET 26 of 28 |
|---|---|---|---|

## ELEMENT CARDS

| EN | NAME | S | LAMBDA | CODE | | 80 |
|---|---|---|---|---|---|---|
| 1 | AIRFRAME | 1 | 367.2 | SS A | | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | 80 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE 1 | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

| EN | NAME | S | LAMBDA | CODE | | 80 |
|---|---|---|---|---|---|---|
| 2 | PROPULSION | 1 | 1603.9. | SS B | | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | 80 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE 1 | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

| EN | NAME | S | LAMBDA | CODE | | 80 |
|---|---|---|---|---|---|---|
| 3 | ELECTRICAL | 1 | 634.7 | SS C | | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | 80 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE 1 | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

SLVS RELIABILITY SIMULATION DATA (Sheet 26 of 28)
FIGURE 5-3

| LEAR SIEGLER, INC. INSTRUMENT DIVISION | RAPID DTF III | PROBABILISTIC SYSTEM MODE ANALYSIS | SHEET 27 of 28 |
|---|---|---|---|

ELEMENT CARDS

| EN | NAME | S | LAMBDA | CODE | | 80 |
|---|---|---|---|---|---|---|
| 4 | GUID CONTR | 1 | 44131.3 | SS D | | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | FAILURE 1 | 1. | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

| EN | NAME | S | LAMBDA | CODE | | 80 |
|---|---|---|---|---|---|---|
| | | | | | | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

| EN | NAME | S | LAMBDA | CODE | | 80 |
|---|---|---|---|---|---|---|
| | | | | | | 6 |

| | MODE NAME | C | | MODE NAME | C | | MODE NAME | C | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 2 | | | 3 | | | 6 |
| 4 | | | 5 | | | 6 | | | 6 |
| 7 | | | 8 | | | 9 | | | 6 |

SLVS RELIABILITY SIMULATION DATA (Sheet 27 of 28)
FIGURE 5-3

| LEAR SIEGLER, INC. INSTRUMENT DIVISION | RAPID DTF III A | PROBABILISTIC SYSTEM MODE ANALYSIS | SHEET 28 of 28 |
|---|---|---|---|

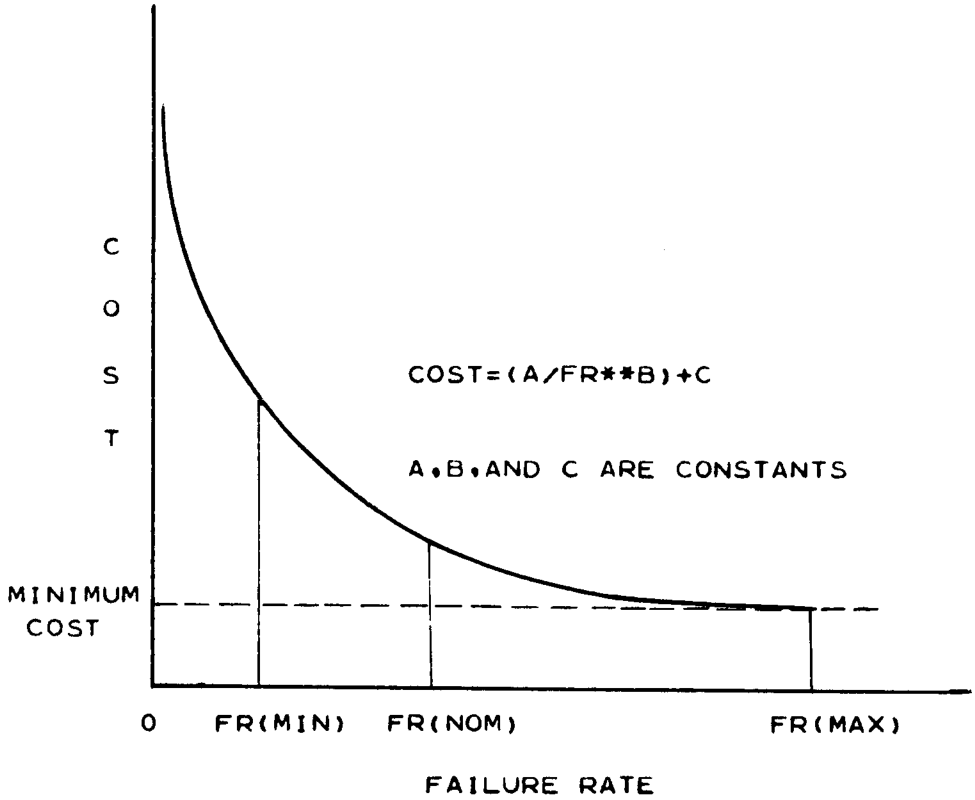
## ELEMENT K FACTOR CARDS

| EB | EE | K FACTOR | K FACTOR | K FACTOR | K FACTOR | K FACTOR | 80 |
|---|---|---|---|---|---|---|---|
| 1 | 3 | 200. | 100. | 100. | 100. | 50. | 7 |
| | | 1. | 1. | 50. | 200. | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |

| EB | EE | K FACTOR | K FACTOR | K FACTOR | K FACTOR | K FACTOR | 80 |
|---|---|---|---|---|---|---|---|
| 4 | 4 | 1. | 1. | 1. | 1. | 1. | 7 |
| | | 1. | 1. | 1. | 1. | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |

| EB | EE | K FACTOR | K FACTOR | K FACTOR | K FACTOR | K FACTOR | 80 |
|---|---|---|---|---|---|---|---|
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |
| | | | | | | | 7 |

FIGURE 5-3 SLVS RELIABILITY SIMULATION DATA (Sheet 28 of 28)




ELEMENT COST/FAILURE RATE RELATIONSHIPS
FIGURE 5-4

| LEAR SIEGLER, INC. INSTRUMENT DIVISION | GREAT DTF I | FUNCTION EXTREMUM ANALYSIS | SHEET 1 OF 3 |
|---|---|---|---|

**PROBLEM DESCRIPTION CARDS**

| NAME OF ORIGINATOR (cols 2–15) | PROBLEM NAME (cols 21–60) | DATE (cols 71–78) | Card (col 80) |
|---|---|---|---|
| NASA NASW-938 | SLVS OPTIMIZATION | 9 14 65 | 1 |

| EXTREMUM | GAMMA | X | C | E | S | WEIGHT | I | R | Card (col 80) |
|---|---|---|---|---|---|---|---|---|---|
| MINIMUM | 1.4 | 22 | 1 | 1 | 99 | 2.0 | 0 | 1 | 2 |

| NS | FUNCTION ANALYZED | Card (col 80) |
|---|---|---|
| 4 | | 3 |
| | THE OBJECTIVE FUNCTION VALUE IS COMPUTED BY THE SUBROUTINE ECON. | 3 |
| | THE CONSTRAINING FUNCTION VALUE IS COMPUTED BY THE SUBROUTINE LUV. | 3 |
| | SEE FIGURE 5-6 FOR A LISTING OF FUNCY, THE SUBROUTINE WHICH | 3 |
| | EXECUTES THE ABOVE SUBROUTINES. | 3 |
| | | 3 |
| | | 3 |
| | | 3 |
| | | 3 |
| | | 3 |
| | | 3 |
| | | 3 |

OPTIMIZATION INPUT DATA
FIGURE 5-5 Page 1 of 3

| LEAR SIEGLER, INC. INSTRUMENT DIVISION | GREAT DTF II | FUNCTION EXTREMUM ANALYSIS | SHEET 2 OF 3 |
|---|---|---|---|

## INDEPENDENT VARIABLE CARDS

| VN | NAME | RANGE MINIMUM | RANGE MAXIMUM | INITIAL VALUE | PERCENT ERROR | DIV | 80 |
|---|---|---|---|---|---|---|---|
| 1 | B.P. | 106311. | 195892. | 109201. | 1. | 10 | 4 |
| 2 | B.PNU. | 3200. | 22669. | 3828. | 1. | 10 | 4 |
| 3 | B.HYD. | 346602. | 469539. | 350567. | 1. | 10 | 4 |
| 4 | B.AIRF | 1334. | 6117. | 1488. | 1. | 10 | 4 |
| 5 | B.SEP. | 21501. | 64768. | 22897. | 1. | 10 | 4 |
| 6 | S.P. | 115967. | 215429. | 119176. | 1. | 10 | 4 |
| 7 | S.HYD. | 233195. | 367246. | 237520. | 1. | 10 | 4 |
| 8 | S.AIRF | 905. | 4890. | 1033. | 1. | 10 | 4 |
| 9 | S.PNU. | 35819. | 81550. | 37294. | 1. | 10 | 4 |
| 10 | PROP.U | 1017. | 8568. | 1261. | 1. | 10 | 4 |
| 11 | ELEC. | 103297. | 175932. | 105640. | 1. | 10 | 4 |
| 12 | GUID. | 594. | 3873. | 699. | 1. | 10 | 4 |
| 13 | CABL. | 2457. | 8856. | 2663. | 1. | 10 | 4 |
| 14 | E.TRAN | 3862. | 11820. | 4119. | 1. | 10 | 4 |
| 15 | PROG. | 25943. | 46166. | 26596. | 1. | 10 | 4 |
| 16 | D.G. | 85032. | 121440. | 86207. | 1. | 10 | 4 |
| 17 | S.AMP. | 23137. | 42247. | 23753. | 1. | 10 | 4 |
| 18 | R.G. | 16260. | 32322. | 16779. | 1. | 10 | 4 |
| 19 | AIRF.2 | 266. | 1882. | 367. | 1. | 10 | 4 |
| 20 | PROP.2 | 1203. | 7617. | 1604. | 1. | 10 | 4 |

OPTIMIZATION INPUT DATA
FIGURE 5-5 Page 2 of 3

| LEAR SIEGLER, INC. INSTRUMENT DIVISION | GREAT DTF II | FUNCTION EXTREMUM ANALYSIS | SHEET 3 OF 3 |
|---|---|---|---|

## INDEPENDENT VARIABLE CARDS

| VN (1-2) | NAME (6-11) | RANGE MINIMUM (17-26) | RANGE MAXIMUM (29-40) | INITIAL VALUE (47-56) | PERCENT ERROR (62-67) | DIV (73-76) | 80 |
|---|---|---|---|---|---|---|---|
| 1 | ELEC.2 | 283. | 5916. | 635. | 1. | 10 | 4 |
| 2 | G.CON2 | 42539. | 68022. | 44131. | 1. | 10 | 4 |
| 3 | | | | | | | 4 |
| 4 | | | | | | | 4 |
| 5 | | | | | | | 4 |
| 6 | | | | | | | 4 |
| 7 | | | | | | | 4 |
| 8 | | | | | | | 4 |
| 9 | | | | | | | 4 |
| 10 | | | | | | | 4 |
| 11 | | | | | | | 4 |
| 12 | | | | | | | 4 |
| 13 | | | | | | | 4 |
| 14 | | | | | | | 4 |
| 15 | | | | | | | 4 |
| 16 | | | | | | | 4 |
| 17 | | | | | | | 4 |
| 18 | | | | | | | 4 |
| 19 | | | | | | | 4 |
| 20 | | | | | | | 4 |

OPTIMIZATION INPUT DATA
FIGURE 5-5 Page 3 of 3

```
      EXTERNAL FUNCTION (IEXT,X,Y,IC,C,IFRT,NCON)
      ENTRY TO FUNCY.
      INTEGER IFRT,IEXT,IP,IC,I
      V'S XDIM=SET.,0,0
      P'N NEL(10),NS(10),NT,TT(10),T(10*10*15),FIPT(150,XDIM),C1(10
     1*15),SDA(10*15),R(10*15),LD(46),LS(8),MO,DAY,YR,REL,NAME(750)
     2,A(10*15),B(10*15),CONN(10*15),XMIN(150,XDIM),XMAX(150,XDIM),
     3ACC(50),ITYPE(7),DUMB,CONSTR
      T'H LOOP,FOR  I=1,1,I.G.22
LOOP   FIPT(I)=X(I)
      W'R IFRT.G.40,T'O A1
      EXECUTE ECON.(X,Y)
      W'R IEXT .E.0, T'O A1
      Y=-Y
A1    IP=IFRT-40
      EXECUTE LUV.(R)
      REL=1.-R
      C(1)=REL-CONSTR
      W'R REL.L.CONSTR,T'O A2
      IC(1)=0
      T'O A3
A2    IC(1)=1
A3    W'R IFRT .G.40, T'O A4
      W'R IC(1) .E. 0, T'O A5
      IFRT=3
      T'O A6
A5    IFRT=2
A6    F'N
A4    Y=-C(1)
      T'O A6
      E'N
```

SUBROUTINE FUNCY
FIGURE 5-6

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** SYSTEM SUMMARY ***

** SYSTEM REQUIREMENTS **

MISSION TIME (HOURS)........................... 0.12476

RELIABILITY CONSTRAINT (PERCENT,MINIMUM)........... 80.

** RESULTANT OPTIMAL SYSTEM **

MINIMUM SYSTEM COST (DOLLARS)............. 10061515.63

MISSION RELIABILITY (PERCENT)................. 80.0001

| ELEMENT | ELEMENT COST | ELEMENT MISSION RELIABILITY |
|---|---|---|
| LAUNCH VEHICLE | 10061515.63 | .8000 |
| SLVS 1ST STAGE | 3457470.41 | .9160 |
| BOOSTER PROPULSION | 1246003.38 | .9935 |
| BOOSTER PNEUMATIC | 37680.17 | .9995 |
| BOOSTER HYDRAULIC | 54649.90 | .9845 |
| BOOSTER AIRFRAME | 126027.68 | .9999 |
| BOOSTER SEPARATION | 38471.92 | .9983 |
| SUSTAINER PROPULSION | 831310.06 | .9870 |
| SUSTAINER HYDRAULIC | 36585.46 | .9794 |
| SUSTAINER AIRFRAME | 224943.13 | .9997 |
| SUSTAINER PNEUMATIC | 58374.40 | .9965 |
| 1ST STG. PROP. UTIL. | 47742.19 | .9996 |
| 1ST STG. ELECTRICAL | 69983.20 | .9899 |
| 1ST STG. GUIDANCE | 280822.38 | .9998 |
| 1ST STG. FLT. CONTROL | 404876.66 | .9853 |
| FLT. CONT. CABLING | 9232.20 | .9997 |
| FLT. CONT. EXC. TRANS. | 180.04 | .9996 |
| FLT. CONT. PROGRAMMER | 30319.29 | .9975 |
| FLT. CONT. AUTOPILOT | 365145.13 | .9884 |
| AUTOPILOT DISPL. GYRO | 117115.83 | .9924 |
| AUTOPILOT SERVO AMPL. | 144876.85 | .9977 |
| AUTOPILOT RATE GYRO | 103152.45 | .9983 |
| SLVS 2ND STG. | 1604045.77 | .8734 |
| 2ND STG. AIRFRAME | 165536.89 | .9799 |
| 2ND STG. PROPULSION | 975856.02 | .9172 |
| 2ND STG. ELECTRICAL | 44865.92 | .9793 |
| 2ND STG. GUID. AND CONT. | 417786.94 | .9924 |

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

SLVS 1ST STAGE

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .0000E 00
B= .0000E 00
C= .0000E 00

** RESULTS **

ELEMENT MISSION RELIABILITY (PERCENT)........ .9160

ELEMENT COST (DOLLARS)................. 3457470.41

NOTE- FAILURE RATE,K FACTOR,AND COST PARAMETERS A,B AND C DO NOT APPLY TO THIS ELEMENT DIRECTLY. THIS ELEMENT COST IS A FUNCTION OF ELEMENT COSTS AT LOWER LEVELS OF THE SYSTEM.

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

BOOSTER PROPULSION

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .1458E 08
B= .2793E 02
C= .1246E 07

| ELEMENT FAILURE RATE RANGE | MINIMUM | MAXIMUM |
|---|---|---|
| (FAILURES PER MILLION HRS) | 106311.0 | 195892.0 |

* ENVIRONMENTAL DATA *

| TIME INTERVAL (HOURS) | | | K FACTOR |
|---|---|---|---|
| .00000 | TO | .03750 | 1.0000 |
| .03750 | TO | .03778 | 1.0000 |
| .03778 | TO | .03833 | .0000 |
| .03833 | TO | .07347 | .0000 |
| .07347 | TO | .07772 | .0000 |
| .07772 | TO | .07839 | .0000 |
| .07839 | TO | .08951 | .0000 |
| .08951 | TO | .09222 | .0000 |
| .09222 | TO | .12476 | .0000 |

** RESULTS **

ELEMENT FAILURE RATE (PER MILLION HRS.)....... .1728E 06

ELEMENT MISSION RELIABILITY (PERCENT)........ .9935

ELEMENT COST FOR FAILURE RATE (DOLLARS) 1246003.38

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

BOOSTER PNEUMATIC

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .2855E 00
B= .3610E 01
C= .3727E 05

| | MINIMUM | MAXIMUM |
|---|---|---|
| ELEMENT FAILURE RATE RANGE (FAILURES PER MILLION HRS) | 3200.0 | 22669.0 |

* ENVIRONMENTAL DATA *

| TIME INTERVAL | | (HOURS) | K FACTOR |
|---|---|---|---|
| .00000 | TO | .03750 | 1.0000 |
| .03750 | TO | .03778 | 1.0000 |
| .03778 | TO | .03833 | .0000 |
| .03833 | TO | .07347 | .0000 |
| .07347 | TO | .07772 | .0000 |
| .07772 | TO | .07839 | .0000 |
| .07839 | TO | .08951 | .0000 |
| .08951 | TO | .09222 | .0000 |
| .09222 | TO | .12476 | .0000 |

** RESULTS **

ELEMENT FAILURE RATE (PER MILLION HRS.)...... .1335E 05

ELEMENT MISSION RELIABILITY (PERCENT)........ .9995

ELEMENT COST FOR FAILURE RATE (DOLLARS) 37680.17

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

BOOSTER HYDRAULIC

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .6678E 21
B= .2953E 02
C= .5423E 05

| ELEMENT FAILURE RATE RANGE (FAILURES PER MILLION HRS) | MINIMUM | MAXIMUM |
|---|---|---|
| | 346602.0 | 469539.0 |

* ENVIRONMENTAL DATA *

| TIME INTERVAL (HOURS) | | | K FACTOR |
|---|---|---|---|
| .00000 | TO | .03750 | 1.0000 |
| .03750 | TO | .03778 | 1.0000 |
| .03778 | TO | .03833 | .0000 |
| .03833 | TO | .07347 | .0000 |
| .07347 | TO | .07772 | .0000 |
| .07772 | TO | .07839 | .0000 |
| .07839 | TO | .08951 | .0000 |
| .08951 | TO | .09222 | .0000 |
| .09222 | TO | .12476 | .0000 |

** RESULTS **

ELEMENT FAILURE RATE (PER MILLION HRS.)...... .4134E 06

ELEMENT MISSION RELIABILITY (PERCENT)........ .9845

ELEMENT COST FOR FAILURE RATE (DOLLARS) 54649.90

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

BOOSTER AIRFRAME

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .3460E-11
B= .9062E 01
C= .1260E 06

| ELEMENT FAILURE RATE RANGE (FAILURES PER MILLION HRS) | MINIMUM | MAXIMUM |
|---|---|---|
| | 1334.0 | 6117.0 |

* ENVIRONMENTAL DATA *

| TIME INTERVAL (HOURS) | | | K FACTOR |
|---|---|---|---|
| .00000 | TO | .03750 | 1.0000 |
| .03750 | TO | .03778 | 1.0000 |
| .03778 | TO | .03833 | 1.0000 |
| .03833 | TO | .07347 | .0000 |
| .07347 | TO | .07772 | .0000 |
| .07772 | TO | .07839 | .0000 |
| .07839 | TO | .08951 | .0000 |
| .08951 | TO | .09222 | .0000 |
| .09222 | TO | .12476 | .0000 |

** RESULTS **

ELEMENT FAILURE RATE (PER MILLION HRS.)...... .3768E 04

ELEMENT MISSION RELIABILITY (PERCENT)........ .9999

ELEMENT COST FOR FAILURE RATE (DOLLARS) 126027.68

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

BOOSTER SEPARATION

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .1849E 00
B= .8303E 01
C= .3829E 05

| ELEMENT FAILURE RATE RANGE | MINIMUM | MAXIMUM |
|---|---|---|
| (FAILURES PER MILLION HRS) | 21501.0 | 64768.0 |

* ENVIRONMENTAL DATA *

| TIME INTERVAL (HOURS) | | | K FACTOR |
|---|---|---|---|
| .00000 | TO | .03750 | 1.0000 |
| .03750 | TO | .03778 | 1.0000 |
| .03778 | TO | .03833 | 1.0000 |
| .03833 | TO | .07347 | .0000 |
| .07347 | TO | .07772 | .0000 |
| .07772 | TO | .07839 | .0000 |
| .07839 | TO | .08951 | .0000 |
| .08951 | TO | .09222 | .0000 |
| .09222 | TO | .12476 | .0000 |

** RESULTS **

ELEMENT FAILURE RATE (PER MILLION HRS.)....... .4360E 05

ELEMENT MISSION RELIABILITY (PERCENT)........ .9983

ELEMENT COST FOR FAILURE RATE (DOLLARS) 38471.92

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

SUSTAINER PROPULSION

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .2585E 09
B= .3271E 02
C= .8313E 06

| ELEMENT FAILURE RATE RANGE (FAILURES PER MILLION HRS) | MINIMUM | MAXIMUM |
|---|---|---|
| | 115967.0 | 215429.0 |

* ENVIRONMENTAL DATA *

| TIME INTERVAL | | (HOURS) | K FACTOR |
|---|---|---|---|
| .00000 | TO | .03750 | 1.0000 |
| .03750 | TO | .03778 | 1.0000 |
| .03778 | TO | .03833 | 1.0000 |
| .03833 | TO | .07347 | 1.0000 |
| .07347 | TO | .07772 | 1.0000 |
| .07772 | TO | .07839 | .0000 |
| .07839 | TO | .08951 | .0000 |
| .08951 | TO | .09222 | .0000 |
| .09222 | TO | .12476 | .0000 |

** RESULTS **

ELEMENT FAILURE RATE (PER MILLION HRS.)...... .1685E 06

ELEMENT MISSION RELIABILITY (PERCENT)........ .9870

ELEMENT COST FOR FAILURE RATE (DOLLARS) 831310.06

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

SUSTAINER HYDRAULIC

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .2714E 19
B= .3693E 02
C= .3615E 05

| ELEMENT FAILURE RATE RANGE (FAILURES PER MILLION HRS) | MINIMUM | MAXIMUM |
|---|---|---|
| | 233195.0 | 367246.0 |

* ENVIRONMENTAL DATA *

| TIME INTERVAL | | (HOURS) | K FACTOR |
|---|---|---|---|
| .00000 | TO | .03750 | 1.0000 |
| .03750 | TO | .03778 | 1.0000 |
| .03778 | TO | .03833 | 1.0000 |
| .03833 | TO | .07347 | 1.0000 |
| .07347 | TO | .07772 | 1.0000 |
| .07772 | TO | .07839 | .0000 |
| .07839 | TO | .08951 | .0000 |
| .08951 | TO | .09222 | .0000 |
| .09222 | TO | .12476 | .0000 |

** RESULTS **

ELEMENT FAILURE RATE (PER MILLION HRS.)...... .2677E 06

ELEMENT MISSION RELIABILITY (PERCENT)........ .9794

ELEMENT COST FOR FAILURE RATE (DOLLARS) 36585.46

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

SUSTAINER AIRFRAME

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .5885E-03
B= .4320E 01
C= .2241E 06

| ELEMENT FAILURE RATE RANGE (FAILURES PER MILLION HRS) | MINIMUM | MAXIMUM |
|---|---|---|
| | 905.0 | 4890.0 |

* ENVIRONMENTAL DATA *

| TIME INTERVAL (HOURS) | | | K FACTOR |
|---|---|---|---|
| .00000 | TO | .03750 | 1.0000 |
| .03750 | TO | .03778 | 1.0000 |
| .03778 | TO | .03833 | 1.0000 |
| .03833 | TO | .07347 | 1.0000 |
| .07347 | TO | .07772 | 1.0000 |
| .07772 | TO | .07839 | 1.0000 |
| .07839 | TO | .08951 | .0000 |
| .08951 | TO | .09222 | .0000 |
| .09222 | TO | .12476 | .0000 |

** RESULTS **

ELEMENT FAILURE RATE (PER MILLION HRS.)...... .3758E 04

ELEMENT MISSION RELIABILITY (PERCENT)........ .9997

ELEMENT COST FOR FAILURE RATE (DOLLARS) 224943.13

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

SUSTAINER PNEUMATIC

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .8428E-10
B= .3464E 02
C= .5829E 05

| ELEMENT FAILURE RATE RANGE (FAILURES PER MILLION HRS) | MINIMUM | MAXIMUM |
|---|---|---|
| | 35819.0 | 81550.0 |

* ENVIRONMENTAL DATA *

| TIME INTERVAL (HOURS) | | | K FACTOR |
|---|---|---|---|
| .00000 | TO | .03750 | 1.0000 |
| .03750 | TO | .03778 | 1.0000 |
| .03778 | TO | .03833 | 1.0000 |
| .03833 | TO | .07347 | 1.0000 |
| .07347 | TO | .07772 | 1.0000 |
| .07772 | TO | .07839 | 1.0000 |
| .07839 | TO | .08951 | .0000 |
| .08951 | TO | .09222 | .0000 |
| .09222 | TO | .12476 | .0000 |

** RESULTS **

ELEMENT FAILURE RATE (PER MILLION HRS.)...... .4504E 05

ELEMENT MISSION RELIABILITY (PERCENT)........ .9965

ELEMENT COST FOR FAILURE RATE (DOLLARS) 58374.40

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

1ST STG. PROP. UTIL.

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .2061E 00
B= .2820E 01
C= .4692E 05

| ELEMENT FAILURE RATE RANGE | MINIMUM | MAXIMUM |
|---|---|---|
| (FAILURES PER MILLION HRS) | 1017.0 | 8568.0 |

* ENVIRONMENTAL DATA *

| TIME INTERVAL (HOURS) | | | K FACTOR |
|---|---|---|---|
| .00000 | TO | .03750 | 1.0000 |
| .03750 | TO | .03778 | 1.0000 |
| .03778 | TO | .03833 | 1.0000 |
| .03833 | TO | .07347 | 1.0000 |
| .07347 | TO | .07772 | .0000 |
| .07772 | TO | .07839 | .0000 |
| .07839 | TO | .08951 | .0000 |
| .08951 | TO | .09222 | .0000 |
| .09222 | TO | .12476 | .0000 |

** RESULTS **

ELEMENT FAILURE RATE (PER MILLION HRS.)...... .5286E 04

ELEMENT MISSION RELIABILITY (PERCENT)........ .9996

ELEMENT COST FOR FAILURE RATE (DOLLARS) 47742.19

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

1ST STG. ELECTRICAL

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .3129E 06
B= .2737E 02
C= .6969E 05

| | MINIMUM | MAXIMUM |
|---|---|---|
| ELEMENT FAILURE RATE RANGE (FAILURES PER MILLION HRS) | 103297.0 | 175932.0 |

* ENVIRONMENTAL DATA *

| TIME INTERVAL (HOURS) | | | K FACTOR |
|---|---|---|---|
| .00000 | TO | .03750 | 1.0000 |
| .03750 | TO | .03778 | 1.0000 |
| .03778 | TO | .03833 | 1.0000 |
| .03833 | TO | .07347 | 1.0000 |
| .07347 | TO | .07772 | 1.0000 |
| .07772 | TO | .07839 | 1.0000 |
| .07839 | TO | .08951 | .0000 |
| .08951 | TO | .09222 | .0000 |
| .09222 | TO | .12476 | .0000 |

** RESULTS **

ELEMENT FAILURE RATE (PER MILLION HRS.)...... .1290E 06

ELEMENT MISSION RELIABILITY (PERCENT)........ .9899

ELEMENT COST FOR FAILURE RATE (DOLLARS) 69983.20

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

1ST STG. GUIDANCE

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .1731E-10
B= .7520E 01
C= .2808E 06

| | MINIMUM | MAXIMUM |
|---|---|---|
| ELEMENT FAILURE RATE RANGE (FAILURES PER MILLION HRS) | 594.0 | 3873.0 |

* ENVIRONMENTAL DATA *

| TIME INTERVAL (HOURS) | | | K FACTOR |
|---|---|---|---|
| .00000 | TO | .03750 | 1.0000 |
| .03750 | TO | .03778 | 1.0000 |
| .03778 | TO | .03833 | 1.0000 |
| .03833 | TO | .07347 | 1.0000 |
| .07347 | TO | .07772 | 1.0000 |
| .07772 | TO | .07839 | 1.0000 |
| .07839 | TO | .08951 | .0000 |
| .08951 | TO | .09222 | .0000 |
| .09222 | TO | .12476 | .0000 |

** RESULTS **

ELEMENT FAILURE RATE (PER MILLION HRS.)...... .2451E 04

ELEMENT MISSION RELIABILITY (PERCENT)........ .9998

ELEMENT COST FOR FAILURE RATE (DOLLARS) 280822.38

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

1ST STG. FLT. CONTROL

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .0000E 00
B= .0000E 00
C= .0000E 00

** RESULTS **

ELEMENT MISSION RELIABILITY (PERCENT)........ .9853

ELEMENT COST (DOLLARS)................. 404876.66

NOTE- FAILURE RATE,K FACTOR,AND COST PARAMETERS A,B AND C
DO NOT APPLY TO THIS ELEMENT DIRECTLY. THIS ELEMENT
COST IS A FUNCTION OF ELEMENT COSTS AT LOWER LEVELS
OF THE SYSTEM.

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

FLT. CONT. CABLING

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .2103E-13
B= .1120E 02
C= .9204E 04

| ELEMENT FAILURE RATE RANGE (FAILURES PER MILLION HRS) | MINIMUM | MAXIMUM |
|---|---|---|
| | 2457.0 | 8856.0 |

* ENVIRONMENTAL DATA *

| TIME INTERVAL (HOURS) | | | K FACTOR |
|---|---|---|---|
| .00000 | TO | .03750 | 1.0000 |
| .03750 | TO | .03778 | 1.0000 |
| .03778 | TO | .03833 | 1.0000 |
| .03833 | TO | .07347 | 1.0000 |
| .07347 | TO | .07772 | 1.0000 |
| .07772 | TO | .07839 | 1.0000 |
| .07839 | TO | .08951 | .0000 |
| .08951 | TO | .09222 | .0000 |
| .09222 | TO | .12476 | .0000 |

** RESULTS **

ELEMENT FAILURE RATE (PER MILLION HRS.)...... .4460E 04

ELEMENT MISSION RELIABILITY (PERCENT)........ .9997

ELEMENT COST FOR FAILURE RATE (DOLLARS) 9232.20

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

FLT. CONT. EXC. TRANS.

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .1872E-17
B= .1438E 02
C= .1560E 03

| ELEMENT FAILURE RATE RANGE (FAILURES PER MILLION HRS) | MINIMUM | MAXIMUM |
|---|---|---|
| | 3862.0 | 11820.0 |

* ENVIRONMENTAL DATA *

| TIME INTERVAL (HOURS) | | | K FACTOR |
|---|---|---|---|
| .00000 | TO | .03750 | 1.0000 |
| .03750 | TO | .03778 | 1.0000 |
| .03778 | TO | .03833 | 1.0000 |
| .03833 | TO | .07347 | 1.0000 |
| .07347 | TO | .07772 | 1.0000 |
| .07772 | TO | .07839 | .0000 |
| .07839 | TO | .08951 | .0000 |
| .08951 | TO | .09222 | .0000 |
| .09222 | TO | .12476 | .0000 |

** RESULTS **

ELEMENT FAILURE RATE (PER MILLION HRS.)...... .4690E 04

ELEMENT MISSION RELIABILITY (PERCENT)........ .9996

ELEMENT COST FOR FAILURE RATE (DOLLARS) 180.04

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

FLT. CONT. PROGRAMMER

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .5818E-14
B= .3253E 02
C= .3025E 05

| ELEMENT FAILURE RATE RANGE (FAILURES PER MILLION HRS) | MINIMUM | MAXIMUM |
|---|---|---|
| | 25943.0 | 46166.0 |

* ENVIRONMENTAL DATA *

| TIME INTERVAL (HOURS) | | | K FACTOR |
|---|---|---|---|
| .00000 | TO | .03750 | 1.0000 |
| .03750 | TO | .03778 | 1.0000 |
| .03778 | TO | .03833 | 1.0000 |
| .03833 | TO | .07347 | 1.0000 |
| .07347 | TO | .07772 | 1.0000 |
| .07772 | TO | .07839 | 1.0000 |
| .07839 | TO | .08951 | .0000 |
| .08951 | TO | .09222 | .0000 |
| .09222 | TO | .12476 | .0000 |

** RESULTS **

ELEMENT FAILURE RATE (PER MILLION HRS.)...... .3205E 05

ELEMENT MISSION RELIABILITY (PERCENT)........ .9975

ELEMENT COST FOR FAILURE RATE (DOLLARS) 30319.29

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

FLT. CONT. AUTOPILOT

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .0000E 00
B= .0000E 00
C= .0000E 00

** RESULTS **

ELEMENT MISSION RELIABILITY (PERCENT)........ .9884

ELEMENT COST (DOLLARS)................. 365145.13

NOTE- FAILURE RATE,K FACTOR,AND COST PARAMETERS A,B AND C DO NOT APPLY TO THIS ELEMENT DIRECTLY. THIS ELEMENT COST IS A FUNCTION OF ELEMENT COSTS AT LOWER LEVELS OF THE SYSTEM.

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

AUTOPILOT DISPL. GYRO

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .4369E 02
B= .5318E 02
C= .1170E 06

| ELEMENT FAILURE RATE RANGE (FAILURES PER MILLION HRS) | MINIMUM | MAXIMUM |
|---|---|---|
| | 85032.0 | 121440.0 |

* ENVIRONMENTAL DATA *

| TIME INTERVAL (HOURS) | | | K FACTOR |
|---|---|---|---|
| .00000 | TO | .03750 | 1.0000 |
| .03750 | TO | .03778 | 1.0000 |
| .03778 | TO | .03833 | 1.0000 |
| .03833 | TO | .07347 | 1.0000 |
| .07347 | TO | .07772 | 1.0000 |
| .07772 | TO | .07839 | .0000 |
| .07839 | TO | .08951 | .0000 |
| .08951 | TO | .09222 | .0000 |
| .09222 | TO | .12476 | .0000 |

** RESULTS **

ELEMENT FAILURE RATE (PER MILLION HRS.)...... .9818E 05

ELEMENT MISSION RELIABILITY (PERCENT)........ .9924

ELEMENT COST FOR FAILURE RATE (DOLLARS) 117115.83

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

AUTOPILOT SERVO AMPL.

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .1229E-10
B= .2574E 02
C= .1443E 06

| ELEMENT FAILURE RATE RANGE (FAILURES PER MILLION HRS) | MINIMUM | MAXIMUM |
|---|---|---|
| | 23137.0 | 42247.0 |

* ENVIRONMENTAL DATA *

| TIME INTERVAL (HOURS) | | | K FACTOR |
|---|---|---|---|
| .00000 | TO | .03750 | 1.0000 |
| .03750 | TO | .03778 | 1.0000 |
| .03778 | TO | .03833 | 1.0000 |
| .03833 | TO | .07347 | 1.0000 |
| .07347 | TO | .07772 | 1.0000 |
| .07772 | TO | .07839 | .0000 |
| .07839 | TO | .08951 | .0000 |
| .08951 | TO | .09222 | .0000 |
| .09222 | TO | .12476 | .0000 |

** RESULTS **

ELEMENT FAILURE RATE (PER MILLION HRS.)...... .2943E 05

ELEMENT MISSION RELIABILITY (PERCENT)........ .9977

ELEMENT COST FOR FAILURE RATE (DOLLARS) 144876.85

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

AUTOPILOT RATE GYRO

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .3318E-16
B= .2772E 02
C= .1031E 06

| ELEMENT FAILURE RATE RANGE | MINIMUM | MAXIMUM |
|---|---|---|
| (FAILURES PER MILLION HRS) | 16260.0 | 32322.0 |

* ENVIRONMENTAL DATA *

| TIME INTERVAL (HOURS) | | | K FACTOR |
|---|---|---|---|
| .00000 | TO | .03750 | 1.0000 |
| .03750 | TO | .03778 | 1.0000 |
| .03778 | TO | .03833 | 1.0000 |
| .03833 | TO | .07347 | 1.0000 |
| .07347 | TO | .07772 | 1.0000 |
| .07772 | TO | .07839 | .0000 |
| .07839 | TO | .08951 | .0000 |
| .08951 | TO | .09222 | .0000 |
| .09222 | TO | .12476 | .0000 |

** RESULTS **

ELEMENT FAILURE RATE (PER MILLION HRS.)...... .2205E 05

ELEMENT MISSION RELIABILITY (PERCENT)........ .9983

ELEMENT COST FOR FAILURE RATE (DOLLARS) 103152.45

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

SLVS 2ND STG.

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .0000E 00
B= .0000E 00
C= .0000E 00

** RESULTS **

ELEMENT MISSION RELIABILITY (PERCENT)........ .8734

ELEMENT COST (DOLLARS).................. 1604045.77

NOTE- FAILURE RATE,K FACTOR,AND COST PARAMETERS A,B AND C DO NOT APPLY TO THIS ELEMENT DIRECTLY. THIS ELEMENT COST IS A FUNCTION OF ELEMENT COSTS AT LOWER LEVELS OF THE SYSTEM.

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

### *** ELEMENT SUMMARY ***

2ND STG. AIRFRAME

### ** INPUTS **

#### * COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .1259E-01
B= .2917E 01
C= .1595E 06

| | MINIMUM | MAXIMUM |
|---|---|---|
| ELEMENT FAILURE RATE RANGE (FAILURES PER MILLION HRS) | 266.0 | 1882.0 |

#### * ENVIRONMENTAL DATA *

| TIME INTERVAL (HOURS) | | | K FACTOR |
|---|---|---|---|
| .00000 | TO | .03750 | 200.0000 |
| .03750 | TO | .03778 | 100.0000 |
| .03778 | TO | .03833 | 100.0000 |
| .03833 | TO | .07347 | 100.0000 |
| .07347 | TO | .07772 | 50.0000 |
| .07772 | TO | .07839 | 1.0000 |
| .07839 | TO | .08951 | 1.0000 |
| .08951 | TO | .09222 | 50.0000 |
| .09222 | TO | .12476 | 200.0000 |

### ** RESULTS **

ELEMENT FAILURE RATE (PER MILLION HRS.)...... .1129E 04

ELEMENT MISSION RELIABILITY (PERCENT)........ .9799

ELEMENT COST FOR FAILURE RATE (DOLLARS) 165536.89

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

2ND STG. PROPULSION

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .6555E 00
B= .3433E 01
C= .9540E 06

| | MINIMUM | MAXIMUM |
|---|---|---|
| ELEMENT FAILURE RATE RANGE (FAILURES PER MILLION HRS) | 1203.0 | 7617.0 |

* ENVIRONMENTAL DATA *

| TIME INTERVAL (HOURS) | | | K FACTOR |
|---|---|---|---|
| .00000 | TO | .03750 | 200.0000 |
| .03750 | TO | .03778 | 100.0000 |
| .03778 | TO | .03833 | 100.0000 |
| .03833 | TO | .07347 | 100.0000 |
| .07347 | TO | .07772 | 50.0000 |
| .07772 | TO | .07839 | 1.0000 |
| .07839 | TO | .08951 | 1.0000 |
| .08951 | TO | .09222 | 50.0000 |
| .09222 | TO | .12476 | 200.0000 |

** RESULTS **

ELEMENT FAILURE RATE (PER MILLION HRS.)....... .4814E 04

ELEMENT MISSION RELIABILITY (PERCENT)........ .9172

ELEMENT COST FOR FAILURE RATE (DOLLARS) 975856.02

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

2ND STG. ELECTRICAL

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .8022E 01
B= .1643E 01
C= .3284E 05

| ELEMENT FAILURE RATE RANGE (FAILURES PER MILLION HRS) | MINIMUM | MAXIMUM |
|---|---|---|
| | 283.0 | 5916.0 |

* ENVIRONMENTAL DATA *

| TIME INTERVAL (HOURS) | | | K FACTOR |
|---|---|---|---|
| .00000 | TO | .03750 | 200.0000 |
| .03750 | TO | .03778 | 100.0000 |
| .03778 | TO | .03833 | 100.0000 |
| .03833 | TO | .07347 | 100.0000 |
| .07347 | TO | .07772 | 50.0000 |
| .07772 | TO | .07839 | 1.0000 |
| .07839 | TO | .08951 | 1.0000 |
| .08951 | TO | .09222 | 50.0000 |
| .09222 | TO | .12476 | 200.0000 |

** RESULTS **

ELEMENT FAILURE RATE (PER MILLION HRS.)...... .1167E 04

ELEMENT MISSION RELIABILITY (PERCENT)........ .9793

ELEMENT COST FOR FAILURE RATE (DOLLARS) 44865.92

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ELEMENT SUMMARY ***

2ND STG. GUID. AND CONT.

** INPUTS **

* COST PARAMETERS *

COST=A/(FAILURE RATE.P.B)+C

A= .6919E-02
B= .2190E 02
C= .4175E 06

| ELEMENT FAILURE RATE RANGE (FAILURES PER MILLION HRS) | MINIMUM | MAXIMUM |
|---|---|---|
| | 42539.0 | 68022.0 |

* ENVIRONMENTAL DATA *

| TIME INTERVAL | | (HOURS) | K FACTOR |
|---|---|---|---|
| .00000 | TO | .03750 | 1.0000 |
| .03750 | TO | .03778 | 1.0000 |
| .03778 | TO | .03833 | 1.0000 |
| .03833 | TO | .07347 | 1.0000 |
| .07347 | TO | .07772 | 1.0000 |
| .07772 | TO | .07839 | 1.0000 |
| .07839 | TO | .08951 | 1.0000 |
| .08951 | TO | .09222 | 1.0000 |
| .09222 | TO | .12476 | 1.0000 |

** RESULTS **

ELEMENT FAILURE RATE (PER MILLION HRS.)...... .6154E 05

ELEMENT MISSION RELIABILITY (PERCENT)........ .9924

ELEMENT COST FOR FAILURE RATE (DOLLARS) 417786.94

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** ECONOMICS MODEL ***

```
            EXTERNAL FUNCTION(FL,COST)
            ENTRY TO ECON.
            VECTOR VALUES XDIM=SET,,0,0
            PROGRAM COMMON NEL(10),SS(10),NT,TT(10),T(10*10*15),XIPT(150,
           1XDIM),C1(10*15),SDA(10*15),R(10*15),LD(46),LS(8),MO,DAY,YR,RE
           2L,NAME(750),A(10*15),B(10*15),CONN(10*15),XMIN(150,XDIM),XMAX
           3(150,XDIM),ACC(50),ITYPE(7),Y
            INTEGER N,NS,NE,I,NAME,J,SET.
            DIMENSION NE(27),NAME(750),NS(27)
            BOOLEAN BOOL
            VECTOR VALUES BOOL=1B
            VECTOR VALUES FMT=$2I10,3E10.3,25C1*$
            WHENEVER BOOL
            READ FORMAT FFMT,N,COVER
            VECTOR VALUES FFMT=$I10,E10.3*$
            J=1
            THROUGH Q1,FOR I=1,1,I.G.N
            READ FORMAT FMT,NS(I),NE(I),A(NS(I),NE(I)),B(NS(I),NE(I)),CON
           1N(NS(I),NE(I)),NAME(J),,,NAME(J+24)
Q1          J=J+25
            BOOL=0B
            END OF CONDITIONAL
           R
           R  **SYSTEM COST MODEL**
           R
            COST=COVER
            THROUGH Q2,FOR I=1,1,I.G.N
Q2          COST=COST+CONN(NS(I),NE(I))+(A(NS(I),NE(I))/((FL(NS(I),NE(I))
           1*.00001).P.B(NS(I),NE(I))))
           R
           R
            Y=COST
            FUNCTION RETURN
            END OF FUNCTION
```

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** RELIABILITY MODEL ***

```
           EXTERNAL FUNCTION(SUMTP)
           ENTRY TO LUV.
           DIMENSION BP(100),TP(100),P(30*5),PP(30)
           INTEGER J,NEL,NS,NT,SDA,SET.
           PROGRAM COMMON NEL(10),NS(10),NT,TT(10),T(10*10*15),XIPT(150)
          1,C1(10*15),SDA(10*15),R(10*15)
           EXECUTE BOGY.(SUMTP)
           P(000001,1)=SUMTP
           PP(000001)=1.-SUMTP
           R(000001,000001)=1.-SUMTP
           EXECUTE RAM.(SUMTP)
           P(000002,1)=SUMTP
           PP(000002)=1.-SUMTP
           R(000001,000002)=1.-SUMTP
           BP(1)=P(1,1)
           BP(2)=P(2,1)
           TP(1)=BP(1)
           TP(2)=BP(2)*(PP(1))
           SUMTP=0.
           THROUGH LA,FOR J=1,1,J.G.NS(000001)
LA         SUMTP=SUMTP+TP(J)
           FUNCTION RETURN
           END OF FUNCTION
```

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** RELIABILITY MODEL ***
(CONT.)

```
         EXTERNAL FUNCTION(SUMTP)
         ENTRY TO BOGY.
         DIMENSION BP(100),TP(100),P(30*5),PP(30)
         INTEGER J,NEL,NS,NT,SDA,SET,
         PROGRAM COMMON NEL(10),NS(10),NT,TT(10),T(10*10*15),XIPT(150)
        1,C1(10*15),SDA(10*15),R(10*15)
         EXECUTE PEXP.(P,PP,000002)
         EXECUTE FLTCON.(SUMTP)
         P(000013,1)=SUMTP
         PP(000013)=1.-SUMTP
         R(000002,000013)=1.-SUMTP
         BP(1)=P(1,1)
         BP(2)=P(2,1)
         BP(3)=P(3,1)
         BP(4)=P(4,1)
         BP(5)=P(5,1)
         BP(6)=P(6,1)
         BP(7)=P(7,1)
         BP(8)=P(8,1)
         BP(9)=P(9,1)
         BP(10)=P(10,1)
         BP(11)=P(11,1)
         BP(12)=P(12,1)
         BP(13)=P(13,1)
         TP(1)=BP(1)
         TP(2)=BP(2)*(PP(1))
         TP(3)=BP(3)*(PP(1)*PP(2))
         TP(4)=BP(4)*(PP(1)*PP(2)*PP(3))
         TP(5)=BP(5)*(PP(1)*PP(2)*PP(3)*PP(4))
         TP(6)=BP(6)*(PP(1)*PP(2)*PP(3)*PP(4)*PP(5))
         TP(7)=BP(7)*(PP(1)*PP(2)*PP(3)*PP(4)*PP(5)*PP(6))
         TP(8)=BP(8)*(PP(1)*PP(2)*PP(3)*PP(4)*PP(5)*PP(6)*PP(7))
         TP(9)=BP(9)*(PP(1)*PP(2)*PP(3)*PP(4)*PP(5)*PP(6)*PP(7)*PP(8))
         TP(10)=BP(10)*(PP(1)*PP(2)*PP(3)*PP(4)*PP(5)*PP(6)*PP(7)*PP(8
        1)*PP(9))
         TP(11)=BP(11)*(PP(1)*PP(2)*PP(3)*PP(4)*PP(5)*PP(6)*PP(7)*PP(8
        1)*PP(9)*PP(10))
         TP(12)=BP(12)*(PP(1)*PP(2)*PP(3)*PP(4)*PP(5)*PP(6)*PP(7)*PP(8
        1)*PP(9)*PP(10)*PP(11))
         TP(13)=BP(10)*(PP(1)*PP(2)*PP(3)*PP(4)*PP(5)*PP(6)*PP(7)*PP(8
        1)*PP(9)*PP(10)*PP(11)*PP(12))
         SUMTP=0.
         THROUGH LA,FOR J=1,1,J.G.NS(000002)
LA       SUMTP=SUMTP+TP(J)
         FUNCTION RETURN
         END OF FUNCTION
```

**SLVS OPTIMIZATION OUTPUT**
**FIGURE 5-7**

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** RELIABILITY MODEL ***
(CONT.)

```
           EXTERNAL FUNCTION(SUMTP)
           ENTRY TO FLTCON.
           DIMENSION BP(100),TP(100),P(30*5),PP(30)
           INTEGER J,NEL,NS,NT,SDA,SET.
           PROGRAM COMMON NEL(10),NS(10),NT,TT(10),T(10*10*15),XIPT(150)
          1,C1(10*15),SDA(10*15),R(10*15)
           EXECUTE PEXP.(P,PP,000003)
           EXECUTE AUTOPI.(SUMTP)
           P(000004,1)=SUMTP
           PP(000004)=1.-SUMTP
           R(000003,000004)=1.-SUMTP
           BP(1)=P(1,1)
           BP(2)=P(2,1)
           BP(3)=P(3,1)
           BP(4)=P(4,1)
           TP(1)=BP(1)
           TP(2)=BP(2)*(PP(1))
           TP(3)=BP(3)*(PP(1)*PP(2))
           TP(4)=BP(4)*(PP(1)*PP(2)*PP(3))
           SUMTP=0.
           THROUGH LA,FOR J=1,1,J.G.NS(000003)
LA         SUMTP=SUMTP+TP(J)
           FUNCTION RETURN
           END OF FUNCTION
```

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** RELIABILITY MODEL ***
(CONT.)

```
         EXTERNAL FUNCTION(SUMTP)
         ENTRY TO AUTOPI.
         DIMENSION BP(100),TP(100),P(30*5),PP(30)
         INTEGER J,NEL,NS,NT,SDA,SET.
         PROGRAM COMMON NEL(10),NS(10),NT,TT(10),T(10*10*15),XIPT(150)
        1,C1(10*15),SDA(10*15),R(10*15)
         EXECUTE PEXP.(P,PP,000004)
         BP(1)=P(1,1)
         BP(2)=P(2,1)
         BP(3)=P(3,1)
         TP(1)=BP(1)
         TP(2)=BP(2)*(PP(1))
         TP(3)=BP(3)*(PP(1)*PP(2))
         SUMTP=0.
         THROUGH LA,FOR J=1,1,J.G.NS(000004)
LA       SUMTP=SUMTP+TP(J)
         FUNCTION RETURN
         END OF FUNCTION
```

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** RELIABILITY MODEL ***
(CONT.)

```
           EXTERNAL FUNCTION(SUMTP)
           ENTRY TO RAM.
           DIMENSION BP(100),TP(100),P(30*5),PP(30)
           INTEGER J,NEL,NS,NT,SDA,SET.
           PROGRAM COMMON NEL(10),NS(10),NT,TT(10),T(10*10*15),XIPT(150)
          1,C1(10*15),SDA(10*15),R(10*15)
           EXECUTE PEXP.(P,PP,000005)
           BP(1)=P(1,1)
           BP(2)=P(2,1)
           BP(3)=P(3,1)
           BP(4)=P(4,1)
           TP(1)=BP(1)
           TP(2)=BP(2)*(PP(1))
           TP(3)=BP(3)*(PP(1)*PP(2))
           TP(4)=BP(4)*(PP(1)*PP(2)*PP(3))
           SUMTP=0.
           THROUGH LA,FOR J=1,1,J.G.NS(000005)
LA         SUMTP=SUMTP+TP(J)
           FUNCTION RETURN
           END OF FUNCTION
```

SLVS OPTIMIZATION OUTPUT
FIGURE 5-7

STUDY LAUNCH VEHICLE SYSTEM

*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*

*** SYSTEM SUMMARY ***

** SYSTEM REQUIREMENTS **

MISSION TIME (HOURS)........................... 0.12476

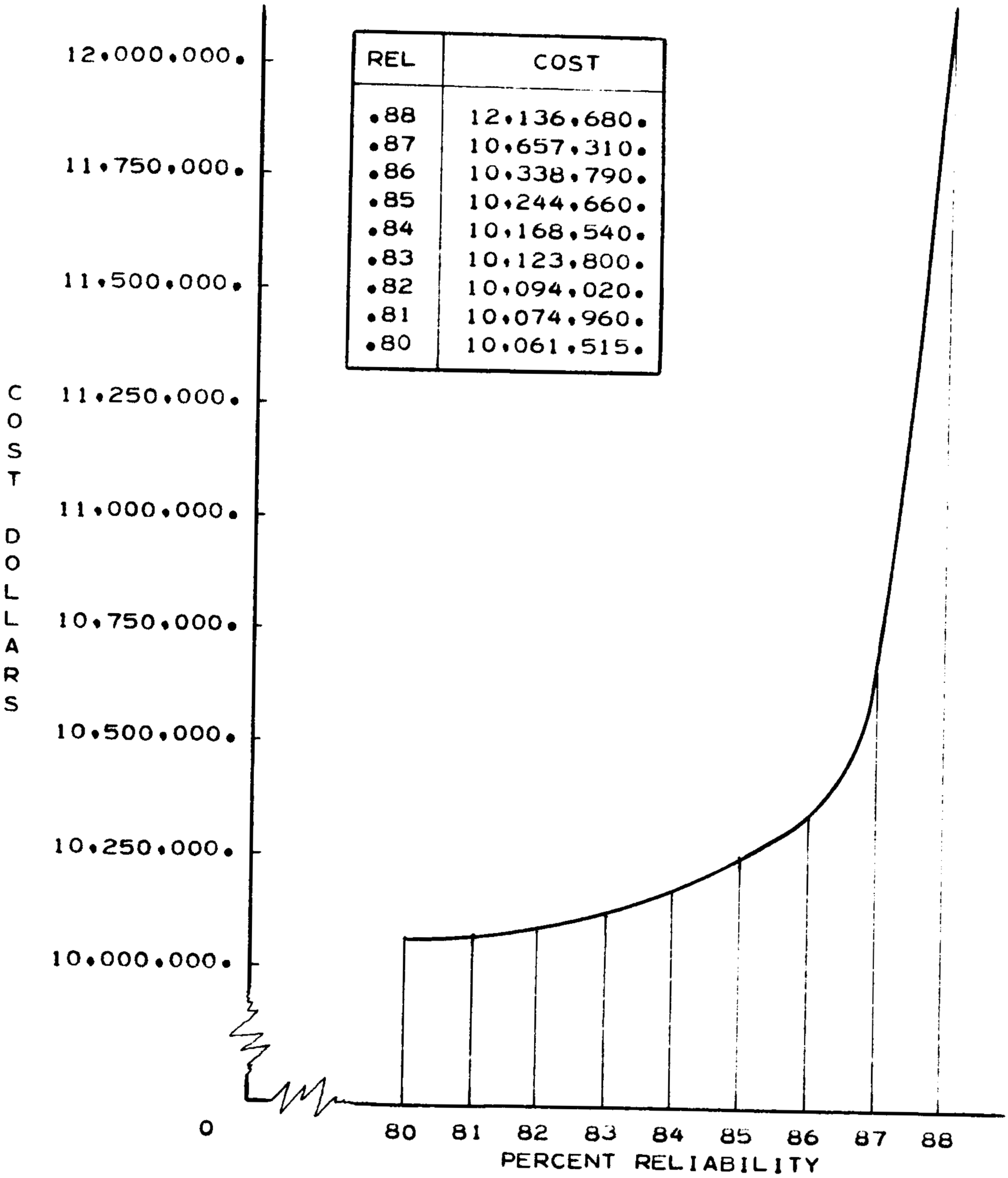
** NOMINAL SYSTEM **

NOMINAL SYSTEM COST (DOLLARS).............. 15036694.00

MISSION RELIABILITY (PERCENT)...................... 88.31

| ELEMENT | ELEMENT COST | ELEMENT MISSION RELIABILITY |
|---|---|---|
| LAUNCH VEHICLE | 15036694.00 | .8831 |
| SLVS 1ST STAGE | 6908694.00 | .9324 |
| BOOSTER PROPULSION | 2493936.00 | .9958 |
| BOOSTER PNEUMATIC | 74541.00 | .9998 |
| BOOSTER HYDRAULIC | 108468.00 | .9868 |
| BOOSTER AIRFRAME | 252126.00 | .9999 |
| BOOSTER SEPARATION | 76590.00 | .9991 |
| SUSTAINER PROPULSION | 1662624.00 | .9907 |
| SUSTAINER HYDRAULIC | 72312.00 | .9817 |
| SUSTAINER AIRFRAME | 448224.00 | .9999 |
| SUSTAINER PNEUMATIC | 116589.00 | .9970 |
| 1ST STG. PROP. UTIL. | 93840.00 | .9999 |
| 1ST STG. ELECTRICAL | 139380.00 | .9917 |
| 1ST STG. GUIDANCE | 561660.00 | .9999 |
| 1ST STG. FLT. CONTROL | 808404.00 | .9876 |
| FLT. CONT. CABLING | 18409.00 | .9997 |
| FLT. CONT. EXC. TRANS. | 312.00 | .9996 |
| FLT. CONT. PROGRAMMER | 60518.00 | .9979 |
| FLT. CONT. AUTOPILOT | 729165.00 | .9901 |
| AUTOPILOT DISPL. GYRO | 234062.00 | .9933 |
| AUTOPILOT SERVO AMPL. | 288749.00 | .9981 |
| AUTOPILOT RATE GYRO | 206354.00 | .9986 |
| SLVS 2ND STAGE | 3128000.00 | .9471 |
| 2ND STG. AIRFRAME | 319056.00 | .9931 |
| 2ND STG. PROPULSION | 1908080.00 | .9704 |
| 2ND STG. ELECTRICAL | 65688.00 | .9881 |
| 2ND STG. GUID.AND CONT. | 835176.00 | .9945 |

NOMINAL STUDY LAUNCH VEHICLE SYSTEM
FIGURE 5-8




| REL | COST |
|---|---|
| .88 | 12,136,680. |
| .87 | 10,657,310. |
| .86 | 10,338,790. |
| .85 | 10,244,660. |
| .84 | 10,168,540. |
| .83 | 10,123,800. |
| .82 | 10,094,020. |
| .81 | 10,074,960. |
| .80 | 10,061,515. |

SLVS COST VS RELIABILITY
FIGURE 5-9